Signal Sources

Subsection
8160A Programmable Pulse Generator

Stuff for rich people... but superlative!

Surprise!

You are mad

You said us that:

- *you renounced to buy the 8160A in favor of the 8165A because you didn't like it;*
- *you said that the 8160A is only a disguised 8015A that you hate;*
- *you said that you hate to work on those 1000-transistor gears;*

and now you come up with …the 8160A?

Well guys, the point is that part of my hate for this instruments is due to the fact that I don't understand their circuits and, like any human being, I tend to detest what I cannot understand…

But working on the 8165A partly changed the situation, because it forced me to study and thus to understand. It isn't yet love, but…

In addition, the Devil does its job, and offered me an 8160A for 87 euros plus 15 for shipment. Hard to resist… Obviously, it is neither in perfect condition, so I expect new days of fightings. But today it arrived and I can't wait to get my hands on it.

8160A Pulse Generator

Preconceptions?

It arrived!

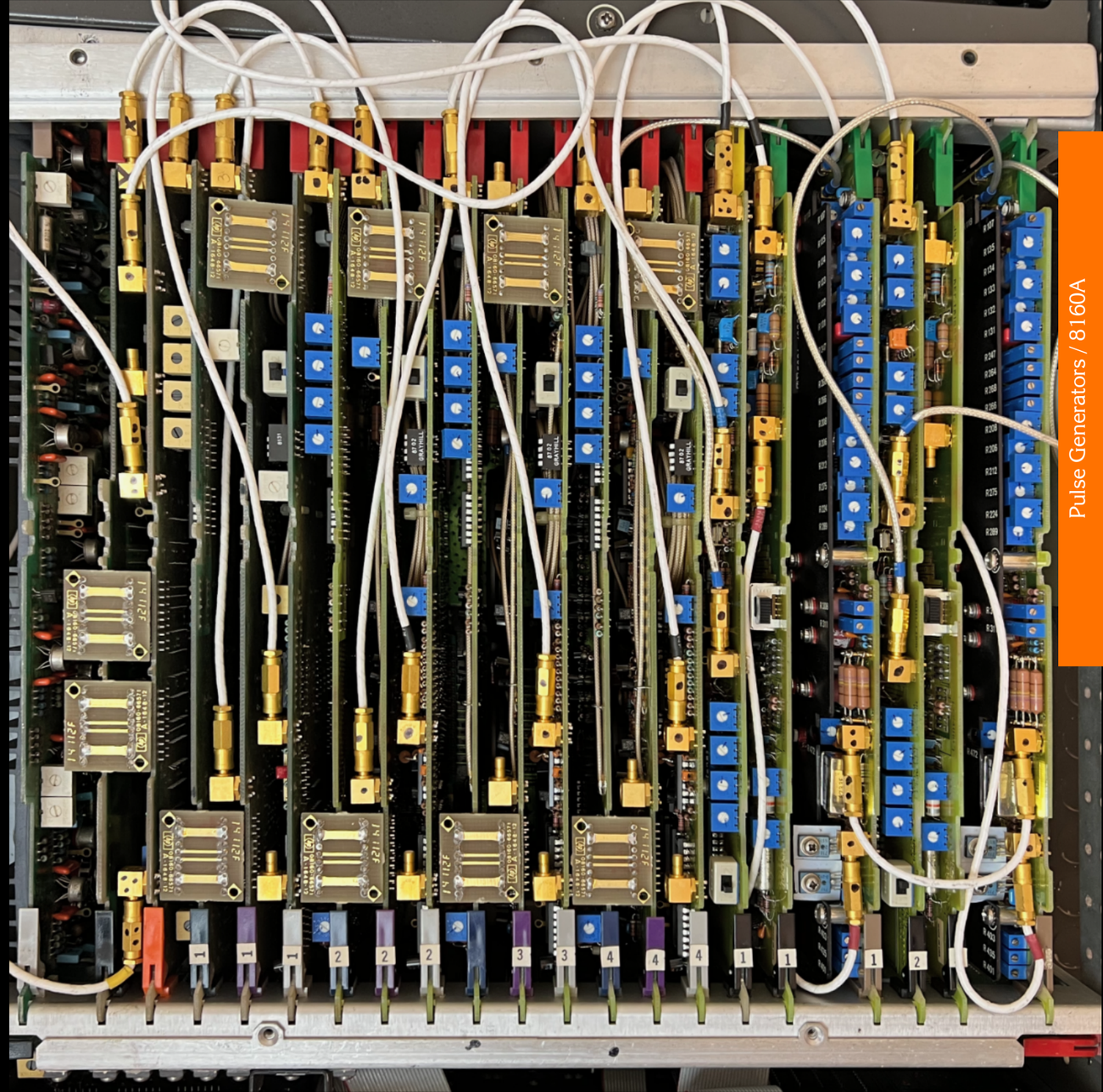
After the experience with the 8015A, the 8012B and the 8165A, I admit I am prejudiced. I expect that the 8160A is only a disguised 8015A, with just a nicer digital interface and crowds of discrete transistors everywhere, in a low-cost arrangement. I am not very excited by it, and I left it in the garage for some days, while finishing with the 8165A.

Now it's time to carry it home. In my house there is an elevator, but from the garage to the elevator there are two flights of stairs. This unit is complete, except the side panels, so it lacks also the transportation handle, and I can feel all its 20+ kg weight bringing it to my bench. Strange, I think, what did they pack inside to make it so heavy?

Finally it lays on the workbench. Its conditions is not perfect but not terrible either. Let's give it an electroshock and watch what it happens. The unit starts. For one second the display appears confused, but then the software cleans it up and set it properly. The fan is very noisy; I can understand that it is not a small one. The user interface responds coherently and every parameter can be set. The experience with the 8165A helps me understanding its simple and rational logic. Some keys are uncertain; no problem, I will clean them. But no output at all.

Wonders Inside

I decide to give a look inside the box. The cover is the typical HP, just a screw to slide it out. And, like in the fairy tales, this is a moment for my mouth to open in an "oooh" of wonder. The look is wondrous, as shown in the photo on the facing page; this is a true product of the GREAT Hewlett-Packard I love! The feared ghost of the 8015A runs away terrified like a vampire faced with garlic, while I am ashamed of my petty prejudices and erase the silly things I had already written…



First attempts

As usual, I will give you the repair details later, but I want to record here first attempts' story.

Last night I studied a little the manual discovering some interesting things, like:

- **bus structure**: the motherboard is almost purely passive, and the connectors where the boards are inserted are wired simply in parallel to each other. It makes me think that the boards can be inserted in any position.
- **building blocks**: the 8160 is based on a building block named **Time Interval** that can be used with two functions: **delay** and double pulse or **width**. Each Time Interval is physically composed by three boards, linked together on the upper side by two small PCB bridges. Some switches allow to chose their role. My unit has Option 020, i.e., a second B channel in addition to A. Thus it has in total four Time Interval blocks. This let me hope I can use them as spare parts, to obtain at least one working channel.

The boards are controlled by the interconnection bus, but the signals pass among them by mean of **shielded cables** and hi-quality **RF connectors**. That makes repairs easier and gives me an idea.

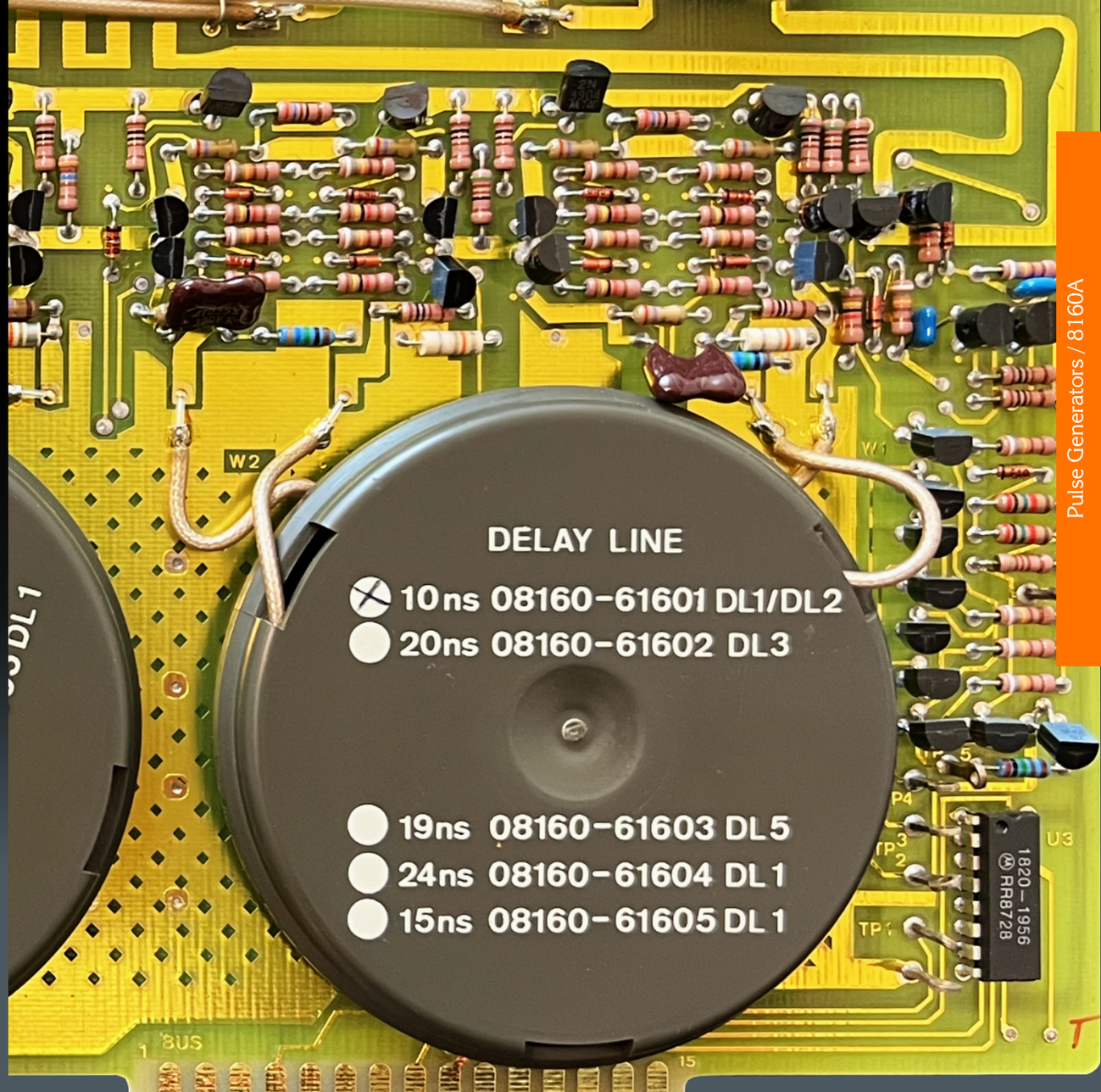
I check the signals on the RF connectors I observed that:

- the signals are just small spikes;
- it seems that at least channel A WIDTH module is not OK.

So I redirect the channel A DELAY output cable to channel B WIDTH module, and… wow, it goes! A signal is produced on channel B. I can manage the global PERiod parameter, the DELAY on channel A, and WIDTH and amplitude parameters on channel B. I am surprised of the results; everything works and the 8160A turns out to be extremely precise. I can change period, delay, pulse width, leading edge, trailing edge, HI output level, LO output level, signal true/inverted, 50 ohm/1k. Even the frequency stability is excellent for a free oscillator: less than 1 Hz/minute @10 KHz after 30 minutes warm-up. Wonderful! With the same technique, I can check also channel A slope control and output stage. They are OK.

I was expecting an imprecise and unstable device, but the results say the opposite: this is really a precision instrument, and I am going to afford the repair with much more enthusiasm than I started.

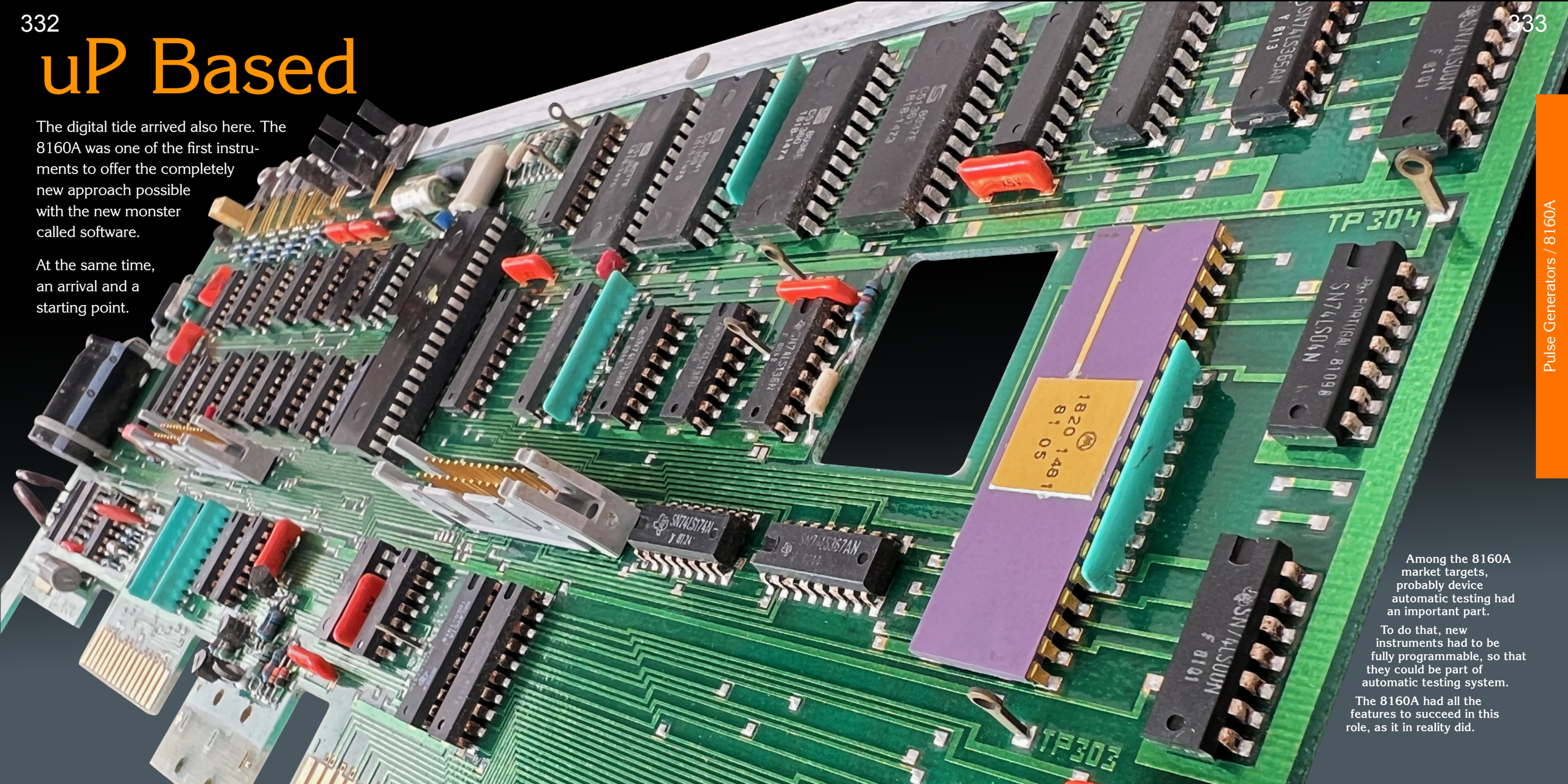
Photo: besides the high number of transistors, the 8160A design is mostly digital oriented, even when combining analog elements, like delay lines. Here in the photo, one of delay lines based on coaxial cable chunks (2 x 10 ns).



uP Based

The digital tide arrived also here. The 8160A was one of the first instruments to offer the completely new approach possible with the new monster called software.

At the same time, an arrival and a starting point.



Among the 8160A market targets, probably device automatic testing had an important part.

To do that, new instruments had to be fully programmable, so that they could be part of automatic testing system.

The 8160A had all the features to succeed in this role, as it in reality did.

8160A Specifications

Introduction

Introduced in 1979, the Hewlett-Packard model 8160A was a fully **programmable** 50 MHz pulse generator designed for high performance applications on the bench and in automatic systems. In the word *programmable*, there is already an important world of novelties differently from its 8015A predecessor, which certainly could not set knobs and switches by remote!

It was available with single (standard) or dual (option 020) output channels, capable of providing 20 V, 6 ns variable transition time pulses, suitable for the majority of testing requirements.

It combined what at the time was high accuracy with then new, microprocessor-based control capabilities. Model 8160A represented hence a significant departure from its pulse generator predecessors, like, indeed, the reviled 8015A.

HP claimed that pulses could be set up without a measuring instrument to adjust each of its parameters **for the first time**, but this partly a **fake**, if you take in account our 8165A. Pulse parameters could be directly entered as numerical quantities using the 8160A's keyboard, and were then displayed on LED's, like in the 8165A. Also the statement that "*…the desired pulse are generated with an unmatched accuracy of 1-3%…*" was not completely true: the 8165A could perform much better, thanks to its PLLs, at least for frequency. Frequency, however, is not the only parameter, and if you consider also pulse width, delay and slopes and how precisely you can modify them, we are in the presence of a true champion, as we are going to see.

So HP could state that the advanced, easy-to-use HP-IB interface brought model 8160A's high accuracy pulses to automatic testing applications. All parameters and operating modes were finally remotely programmable using simple, straight-forward command sequences made possible by the micro-processor, and faster, easier program generation and reduced software costs were direct benefits.

Photo: the 8161A, the "big brother" of the 8160A, is almost identical from outside, but it reaches 100 MHz instead of 50. In return, its output is limited to 5V instead of 20. This beautiful photo is due to courtesy of SGLabs, one of the most important Italian reference points for electronic instruments.



Precision Pulses

Precision Pulse Generation

Model 8160A provides precision control over all parameters of its 50 MHz, 20 V output pulse. Leading and trailing edge transition times may be independently programmed down to 6 ns. With ratios up to 20:1 possible, triangular and sawtooth waveforms are easily generated.

Variable transition times enable you to make an exact match between the output pulse and the rise/fall time requirements of the application. In systems applications, for example, decreasing pulse edge speeds vastly reduce reflections.

Direct entry of the high and low levels of the output pulse enables easy simulation of logic signals. Pulse width is variable from 10 ns to 1 s, and delay shifts the output pulse in relation to the trigger output.

Double pulse mode is also provided, and when two output channels are included (Option 020), double pulse can be independently selected on either or both channels.

Accuracy & Precision

I don't want to start again with the Accuracy & Precision story; you can go back to see it more times discussed in this book. I don't know how HP chose the term "Precision", but I can tell you that the 8160A allows to define the produced pulses with extreme accuracy and precision, down to less than one nanosecond. Most of that is obtained in an analog way, i.e., with delay lines, but, having a set of pre-tuned delay lines available, it operates in a digital way (a line is inserted or not).

Period accuracy is not exceptional (see the digital counter of the Tektronix 2445B here in the photo, not showing 50.000 us), but, for an instrument like this, I believe that 1-3% accuracy/precision **over all** the pulse parameters allows us to call it an **exceptionally precise** pulse generator, as reflected in its price, as we will see later.

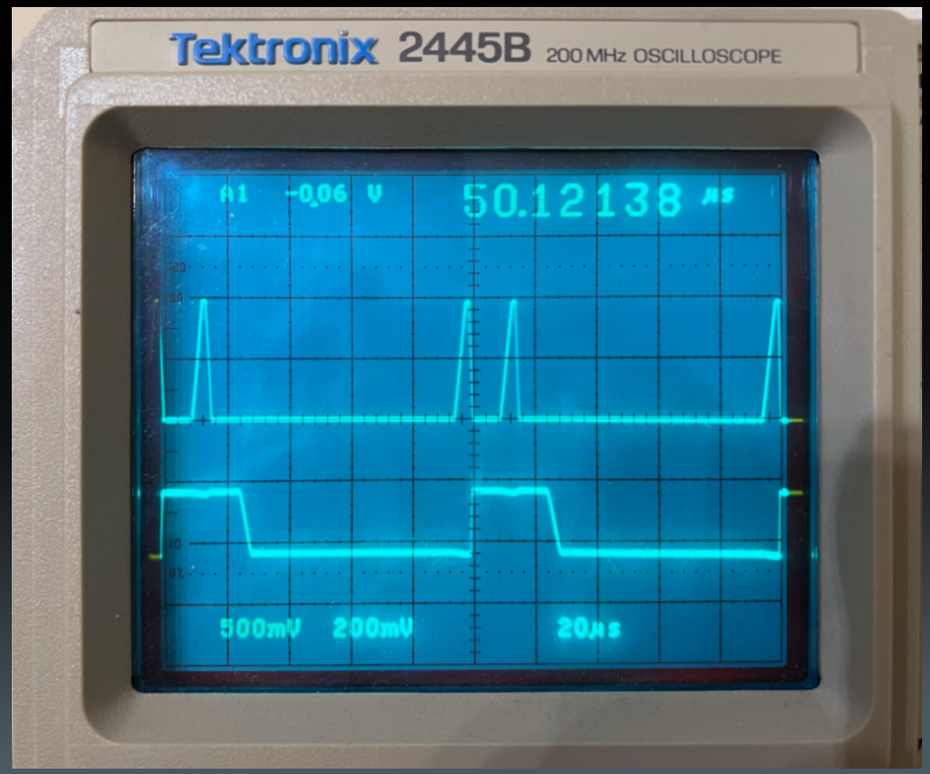
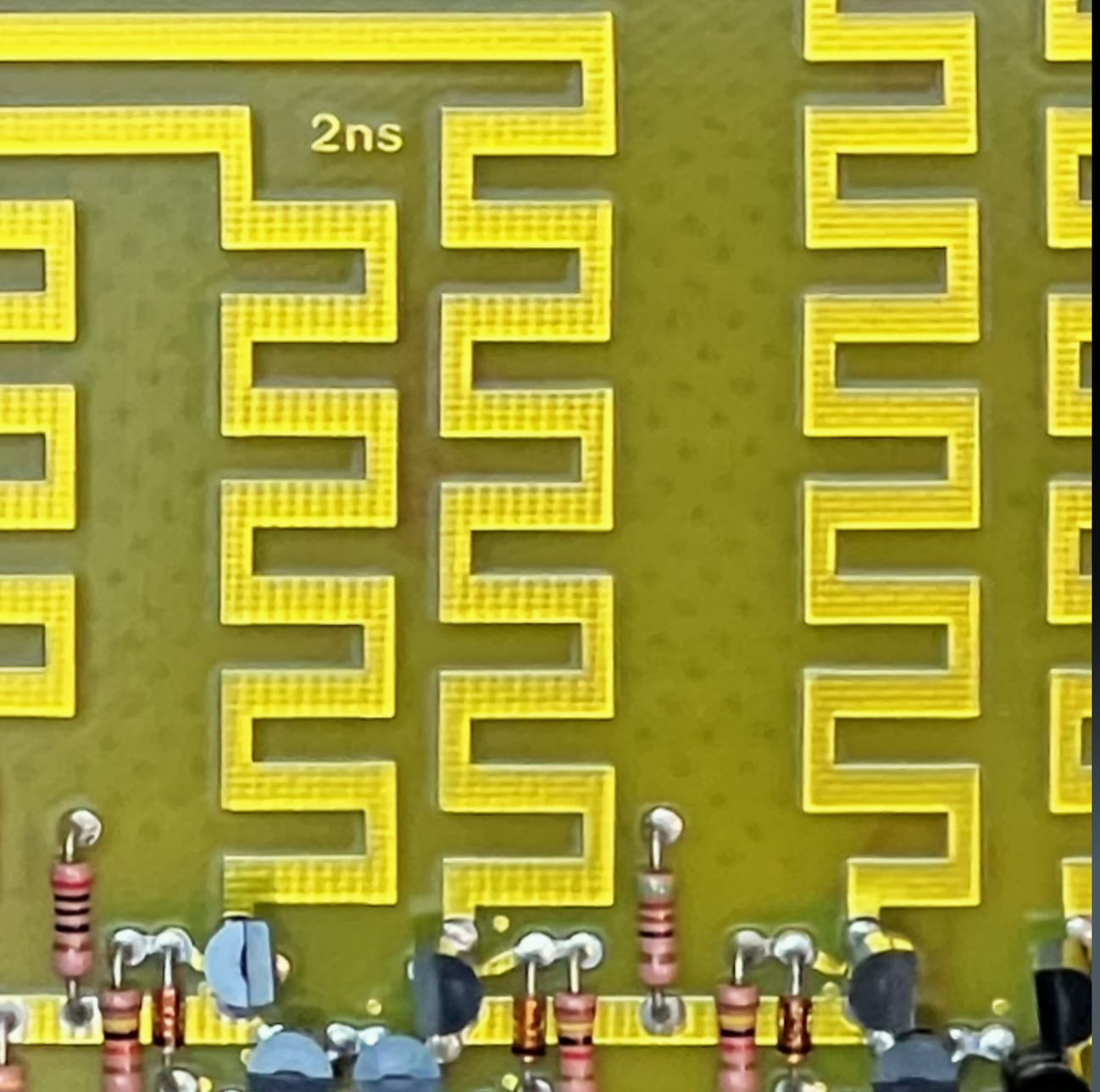


Photo: the 8160A allows to define produced pulses with extreme "precision", with the term used in the widest and most intuitive meaning. You need a good scope, to appreciate how flexible and "precise" it is.



New-Trend Design

Microprocessor-based instrument control

The microprocessor is the center of a new control scheme designed to promote the highly accurate pulse generating hardware. Pulse parameters are directly entered via the instrument's keyboard, and are then displayed on numeric LED's with 3-digit resolution.

In bench applications, the vernier controls, externally similar to those we described for the 8165A, give you a fine adjust capability to 'tweak-in' any pulse parameter. You can increment or decrement the selected parameter either in single steps or automatically at one of two speeds.

Error detection by the microprocessor further simplifies pulse setup by solving the old problem of incompatible settings. Should pulse width exceed pulse period, for example, the microprocessor indicates a TIMING error. All possible mis-settings are detected and the type of error is indicated to aid rapid correction.

Counted burst.

Using Burst Mode a predetermined number of pulses is generated independent of frequency. Bursts from 0 to 9999 pulses in length may be produced, and can be triggered via an external signal, manually or with an HP-IB command.

HP-IB Programming

Microprocessor control over all interface functions makes remote programming as easy and straight-forward as manual control. Like the 8165A, the 8160A employs keystroke programming so that data entry via the HP-IB is an exact simulation of manual entry. Bus commands for each front panel key simply replace manual keystrokes.

Photo: as described in the text, 8160A's precision is obtained by mean of calibrated delay lines. The fastest are directly printed on the circuit board, like this for a 2ns-delay.

It Can Store Setups

Parameter storage

The 8160A stores complete parameter and mode information for 9 independent instrument set-ups. Waveforms may be stored and recalled either manually or via the HP-IB.

By utilizing a single command to recall an entire instrument set-up, this feature is an important saver of controller time. In simple repetitive testing applications, storage of test waveforms can even eliminate the need for an external controller.

Storage is ensured by back-upped static RAM, as we still do today, but using old NiCd rechargeable batteries, instead of modern non-rechargeable ones. NiCd batteries don't have a longer life than Lithium and leak acid over the time, so it is advisable to remove them and place the new ones in a safer place. I had to do that, also because, by mistake, I bought them too big…

Active Verniers

We talked a lot about them describing the 8165A; here they are identical, so go back to know more.

Learn mode

When interrogated by the system controller, the 8160A outputs a character string to the interface bus. This string completely describes the pulser's current set-up or any one of its 10 stored parameter sets.

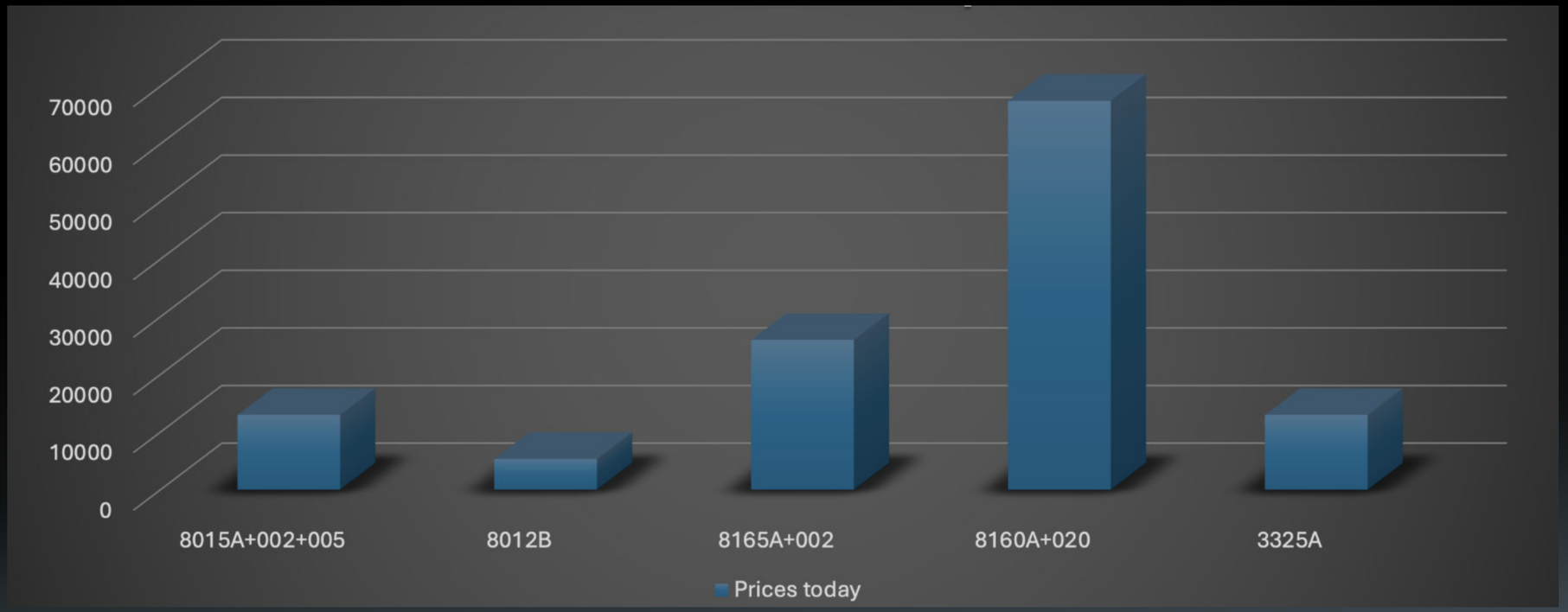
Using Learn Mode, you can enter and try out waveforms manually and then automatically transfer them via the HP-IB to the controller for storage in a program.

HP Journal

The 8160A was described in HP Journal 5/1979 which, as usual, will help us in our historical reconstruction.

Photo: by mistake, I bought on Amazon 6 NiCd batteries but, used to them, I didn't check their dimensions, which sorted out to be much bigger than I expected. Thus, it was impossible to install them it their original position and I had to find a new location for them. Even with the right-sized batteries, it is however advisable to install them in a position where possible acid leaks don't produce damages, adding a suitable connection cable.

Top expensive



Prices today

We have analyzed some vintage **function/pulse generators** that today, in most cases, you can buy for 50/300 Euros on eBay. Some are just collectors items, but most of them are still usable. Maybe they are too big and energy hungry, nevertheless they still have good accuracy and calibrated output, sometimes better than many modern inexpensive equipment. Personally I just love them and use them to restore other instruments which, when repaired, I will use to restore other instruments and so on… Besides our wives opinions, this hobby can contribute to keep our brains in shape and is not too expensive.

Prices at that time

For most equipment described in this book, I tried to give also the original prices converted to today currency, generally with the options that my units have, thanks to several Internet calculators. Often, these prices are surprising, so high to seem impossible. But the 8160A **breaks all records** and reaches the incredible figure of **67,500 euros**! Judging by the number of units offered on eBay, we can assume that, despite its price, it has been a successful model and remained in catalog from 1979 to 1992. Studying it, I can understand its success's reasons and why it was priced so high.

A modular structure

Organization

If we do not consider the back-protruding power supply nor the front panel, the 8160A + Option 020 \is composed by 23 boards, to be inserted in a fully passive motherboard, by mean of direct insertion connections, i.e., with gold plated PCB contacts. This solution is no longer in use, because mating connectors offer in general a better reliability. The bus is relatively position free, and, if necessary, you can use some locations in place of others, but it is advisable to follow exactly the original assignments. Some boards are organized as hat-tricks, and have small PCBs to join them.

Signal main paths use coaxial cable and RF gold plated connectors. Besides these cables, the construction is very clean and there are no flying wires.

Removing the boards

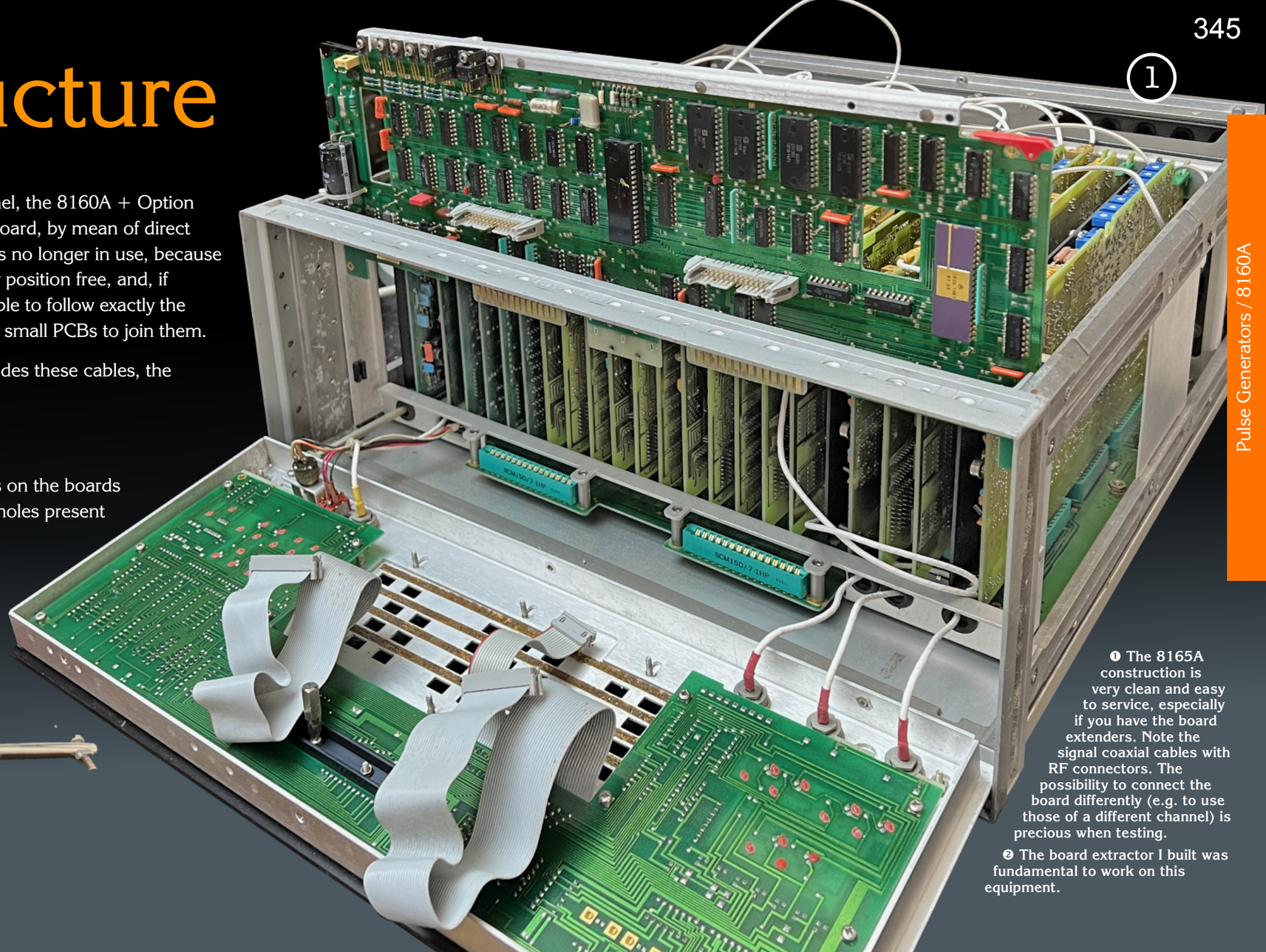
Removing the boards is not easy; don't try to use the small colored levers on the boards upper corners, they break easily. Build a tool like that below and use the holes present in the boards beneath the colored levers.

Beware Connections

I thought it was a legend, but the board edge connectors are terrible, and I wasted one day hunting strange problems to discover finally that they were the culprits. My suggestion is to carefully remove the boards (after decades they may be stuck), then use freely the WD40C (not WD40!) and reinsert and extract the boards more and more times. I passed on them also some very fine sandpaper, removing a lot of problems.



2



1

❶ The 8165A construction is very clean and easy to service, especially if you have the board extenders. Note the signal coaxial cables with RF connectors. The possibility to connect the board differently (e.g. to use those of a different channel) is precious when testing.

❷ The board extractor I built was fundamental to work on this equipment.

Using the 8160A

Fantastic!

The 8160 is a fantastic instrument indeed and allows you to generate a very wide set of signals, with infinite possibilities. In particular, for fast pulses, where other generators are just in the "I-hope-I-go-well" zone, you can produce pulses with micrometrical control.

Caveats

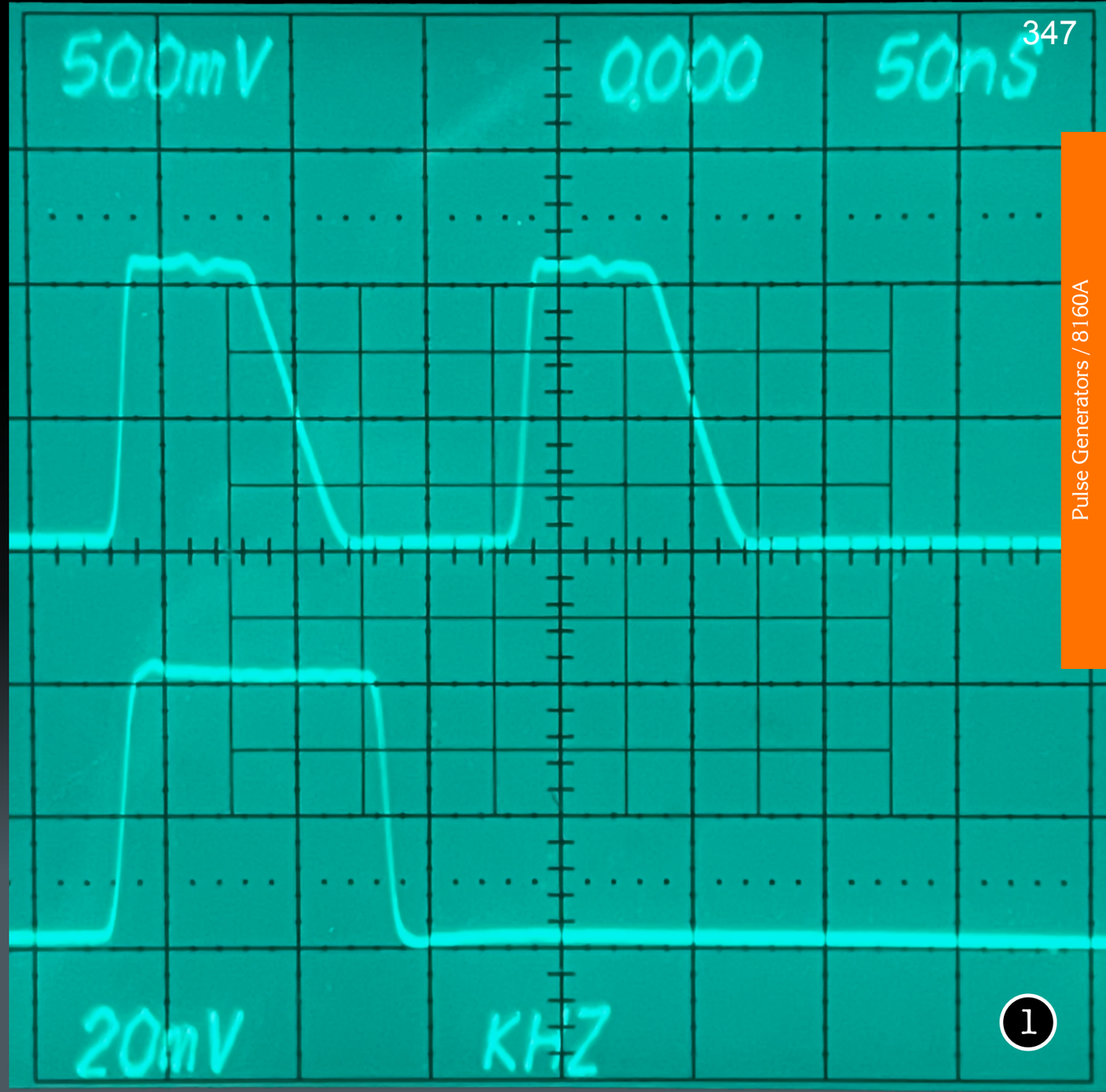
The 8160A user interface is very basic and its main functions can be learned in minutes. It resembles closely the 8165A, apart, obviously, from different functions. Nevertheless, it offers very many possibilities and a minimum reading of the manual is strongly suggested. In particular, note what follows:

- **double pulse**: the 8160A can operate with either **delay** active (variable delay time between trigger and output pulse) or **double pulse** active (a second pulse following every output pulse with variable delay between the two, but not both. There is, therefore, a facility built in to the instrument that tells you which of the two is currently selected. If you press PARAMETER key - DELAY and the PARAMETER field of the display shows DEL^{+}, the + tells you that delay is not active (double pulse is selected). If you wish to select pulse delay, you simply enter the delay parameter as already described and the + will disappear indicating that delay is now active and not double.
- **error indications**: in some instances the reason for the error indication may not be immediately apparent. This is particularly true when double pulse is active.
- **Standard Parameter Set**: if you get lost, you can always recall the Standard Parameter set by pressing RCL followed by data key 0, resetting the parameters as described in the table here.

	CH A	CH B
Input mode	← NORM →	
Slope	← POS →	
Period	← 1 µs →	
Burst	← 10 bt →	
Delay (active)	100 ns	0 ns
Width	100 ns	8 ns
Double pulse (not active)	200 ns	18 ns
Leading edge	10 ns	4 ns
Trailing edge	10 ns	4 ns
High level	1.0 V	+ 0.1 V
Low level	0 V	− 0.1 V
Output	A SEP B	
50 Ω output	A5	B5
Normal output	AN	BN

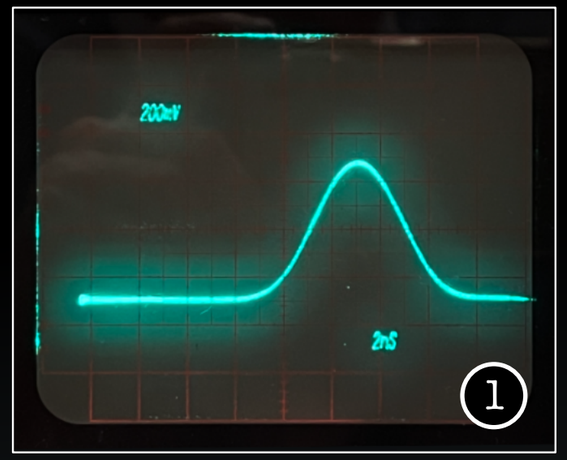
❷

❶ Standard Parameter Set activated by RCL 0 keys.
❷ A beautiful image of the generated pulses from A and B channel, take on a Tektronix 7623A, like most of this chapter.

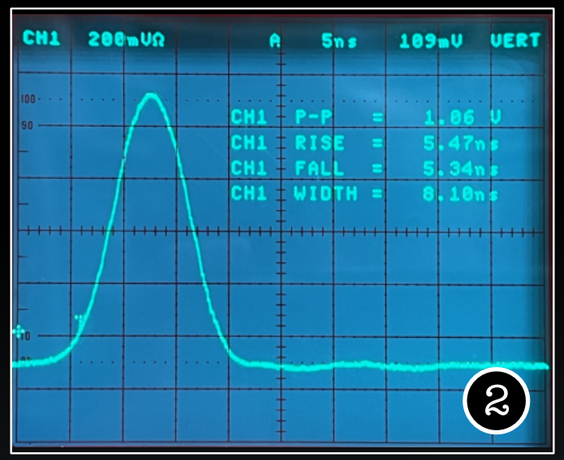


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Family Photos



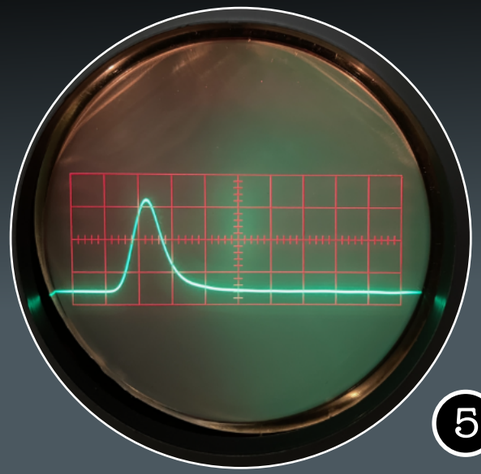
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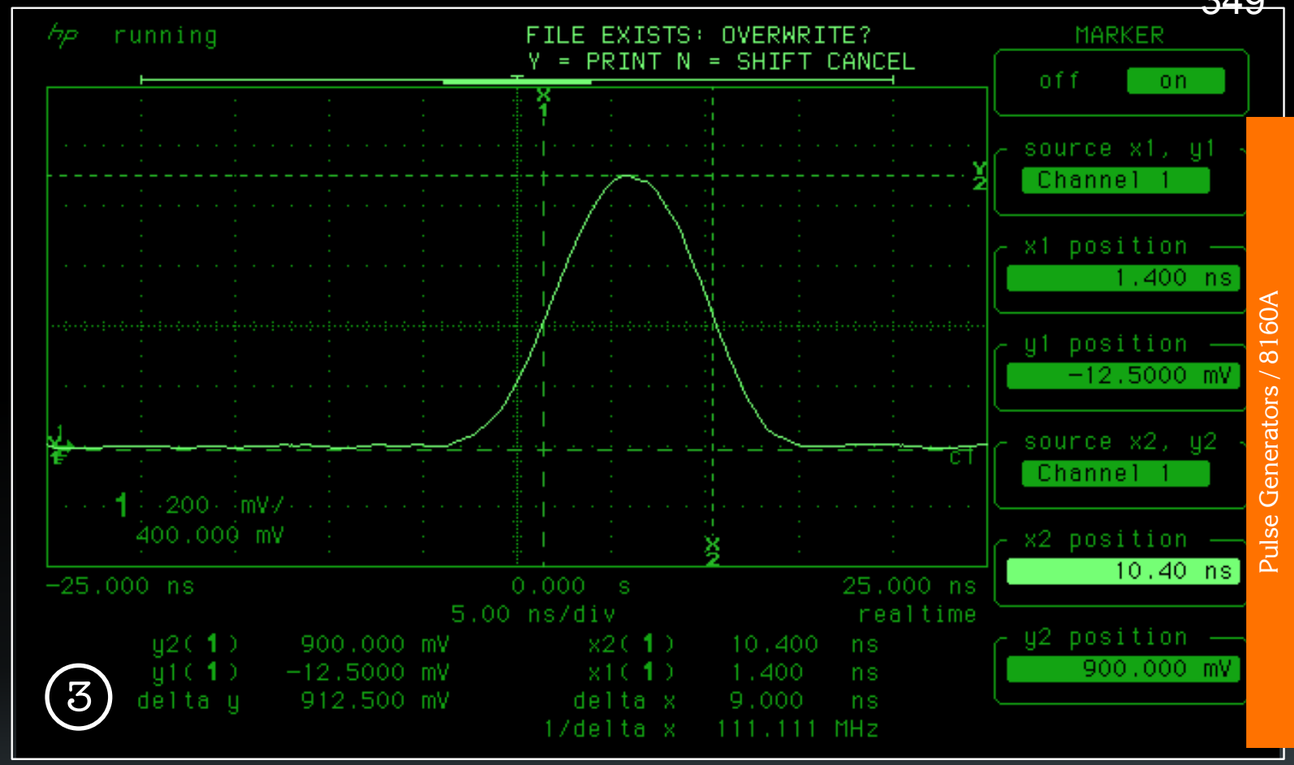
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5



3

Pulse Generators / 8160A

Some Shots with other Members of my Collection

The 8160 was set for 100 us repetition rate, minimum pulse 8 ns with 3 ns leading and trailing edges.

- ❶ Wonderful performance of **Tektronix 7834**, one of my most beloved, in reduced scan mode, @ 2 ns/div in single shot thanks to 7B92A time base and 7A19 vertical amplifier, externally triggered by the 8160A. It could do even better, but the delay line moved the pulse to the right, outside of the screen.
- ❷ The same pulse on **Tektronix 2440**; 500 MSa/s; note the automatic measures almost correct. Obviously, much easier to use than the 7934.
- ❸ The same pulse on **HP 54540A** 1 GSa/s. Top performer, it can also record the screen on floppy, to reduce my editing effort…
- ❹ and ❺ a touch of vintage: Tektronix 545B and 545.

Rate Generation

Accurate Rate Generation

Among the major design goals of the Model 8160A high accuracy, excellent tuning linearity, and low jitter in the rate generator were heralded. If you have read the preceding parts of this story, and in particular that of 8015A and 8165A, you can easily imagine that I was extremely curious about the techniques they used to generate the repetition rate. Here, like in the preceding models, there is the same need for synchronous gating in the burst, external trigger, and gate modes. Hence, the use of an oscillator with an LC tank circuit or feedback loops were precluded, because they would prevent instant starting.

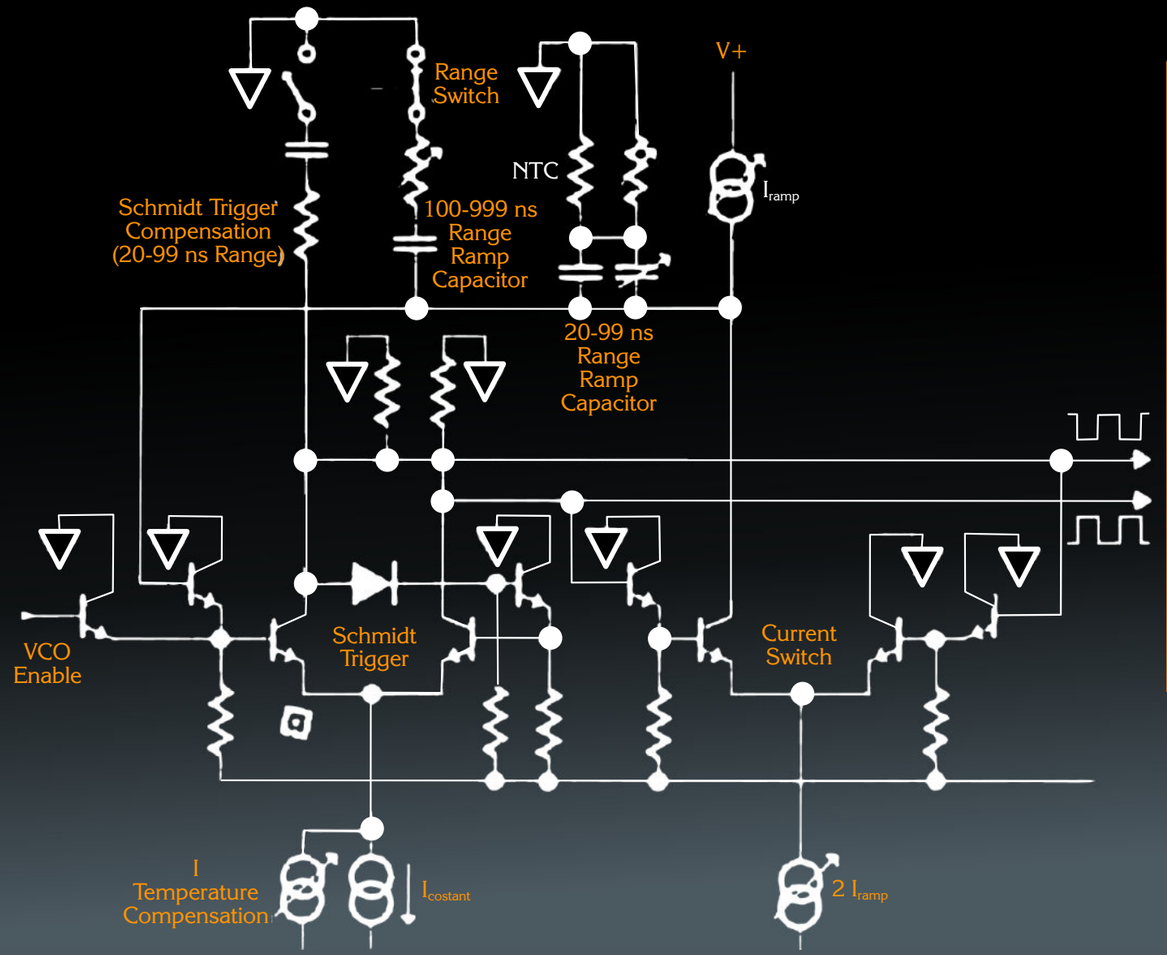
Thus, the solution was again to use a high-frequency, constant-current, capacitor-charge/discharge function-generator circuit for the voltage-controlled oscillator (VCO). That seemed to me in contrast with the performance qualities desired and was the reason of my initial resistance to buy an 8160A.

Studying today this instrument, I can see that HP was clearly convinced that this is the best solution for a repetition rate generator, and how they continued improving its circuit over the years; I started with the rather unstable 8015A and 8012B and then discovered the 8165A, probably better and however stabilized by the PLL.

Here new interesting improvements are put into operation and the results are unexpectedly good: after 30 minutes warm-up, my 8160A drifts about 1 Hz / minute or less (I don't stop to remind: after forty years!).

New secrets

The new secrets are described in the HP Journal. The VCO has only two limited ranges, 20-99 ns and 100-999 ns, avoiding a proliferation of range capacitors. The slower ranges are obtained by dividing down the VCO output frequency, which operates in the 100-999-ns range. The microprocessor determines the values of the tuning signal and the integer N for the 10^n division factor for each period selected. A block diagram of the rate generator system is shown in figure.



Voltage-controlled oscillator operates by capacitance charge and discharge. When the current switch is off, I_{ramp} charges the ramp capacitors until the ramp voltage reaches a level that trips the Schmitt trigger, turning on the current switch. Current $2I_{ramp}$ then discharges the capacitors, while also absorbing I_{ramp}, until the ramp drops below the Schmitt trigger's lower hysteresis level, turning off the current switch. A current controlled by the circuit's temperature varies the Schmitt trigger hysteresis to compensate for temperature-induced variations in propagation delay.

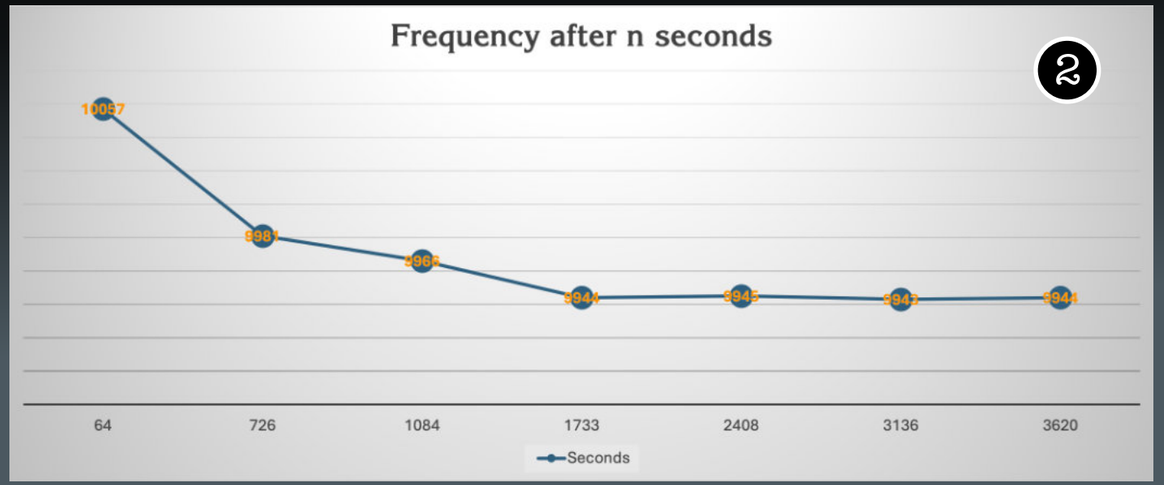
In addition to the reduced ranges, to achieve good tuning linearity in the VCO, four effects had to be accounted for.

The most important of these are

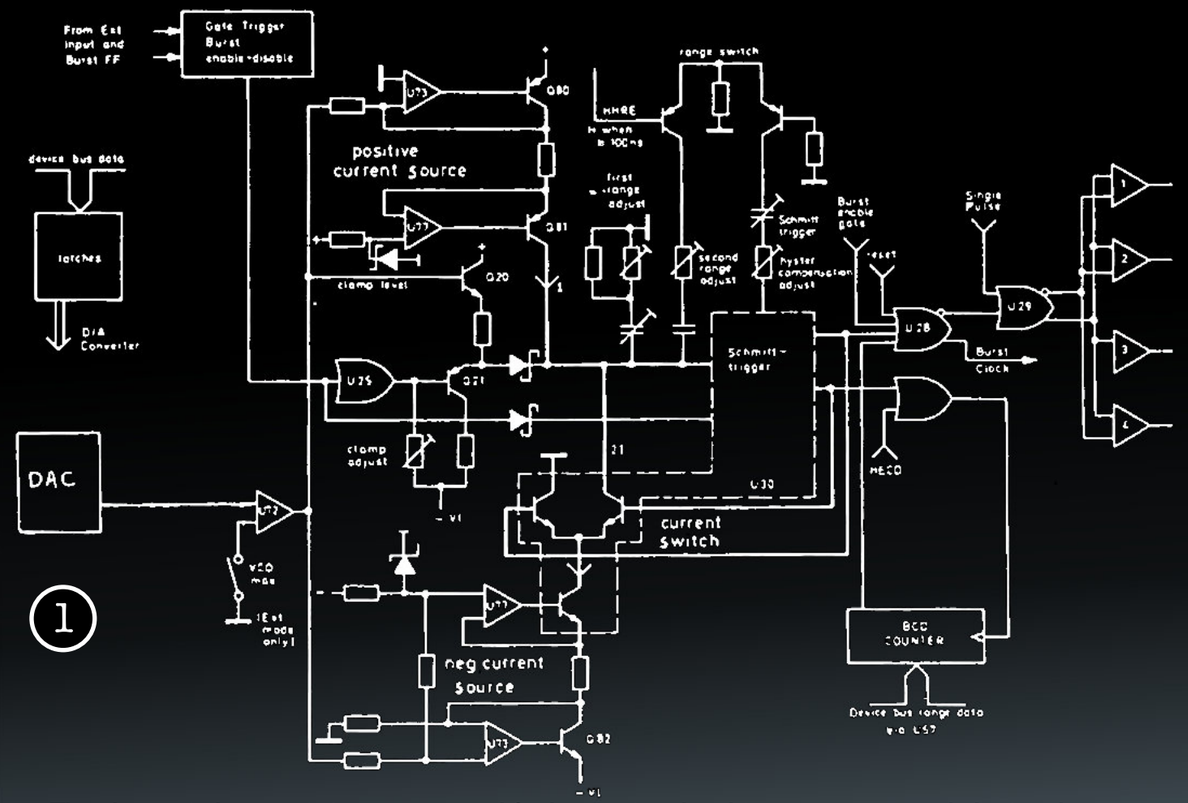
- the **propagation delay** in the Schmitt trigger and the current switch;
- the **change in propagation delay** in the Schmitt trigger as a function of ramp slope, and hence of pulse period.

Compensation for the former is often obtained in other function/pulse generators by adding a small resistor in series with the ramp capacitor. This introduces a step in the ramp capacitor waveform every time the current changes direction, but this compensation is sufficient for period settings greater than 100 ns. For shorter periods, the Schmitt trigger hysteresis is narrowed. These measures make it possible to meet the 2% accuracy specification in the 100-ns-to-999-ns pulse period ranges and the 3% accuracy specification in the 20-99.9-ns pulse-period range, a significant improvement when compared to the 50% non-linearity at the high end of the frequency range of an uncompensated circuit.

The other two effects to be accounted for result from **changes in temperature**. Without compensation, there would be a 5% change in propagation delay over the allowed temperature range (15-35°C) at high repetition rates, and a 0.2%/°C change in Schmitt trigger hysteresis.



❷



The change in hysteresis is compensated for by sensing the chip temperature and altering the temperature-compensation current accordingly. The resistor in series with the ramp capacitor for the 20-99-ns range has a negative-temperature-coefficient to compensate for temperature-induced changes in propagation delay.

Don't Question Me, Please

I tried to understand all this circuit, but it was not easy. After having studied the HP Journal and the manual, don't question me about anyway…

❶ A more detailed block diagram of the VCO. ❷ My frequency stability test @100us period. As you can see, after half a hour, the stability is more than excellent: about 1 Hz, a true record for a free oscillator.

Time Interval Blocks

Building Blocks

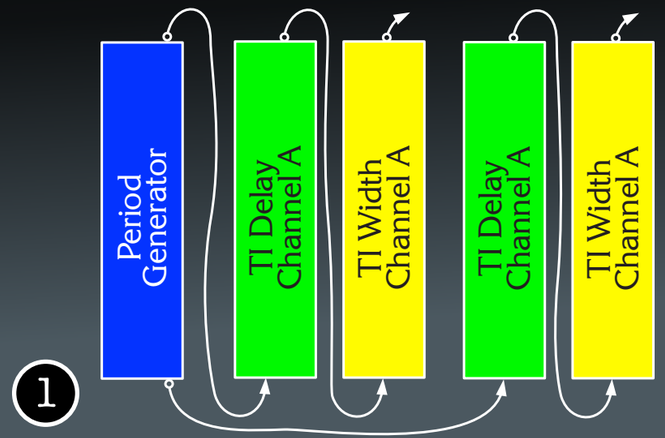
In the 8160A I found something that I never saw before: an ingenious use of a building blocks which minimizes the number of different boards, with benefit also for spare parts stocks and for us, little late reverse engineers, who have less things to understand.

The building block I am interested into is named **Time Interval** that can be used with two different functions, simply selectable by mean of a switch:

- **delay** and double pulse
- **width**.

Each of them can be used for **channel A** or **channel B**, simply changing its physical address by mean of a dip switch. So, if you have Option 020 which adds channel B, you have four TI modules, playing in the following roles: DELAY A, WIDTH A, DELAY B, WIDTH B.

Each Time Interval is physically composed by three boards, linked together on the upper side by two small PCB bridges, so Time Intervals occupy almost a half of the board slots.



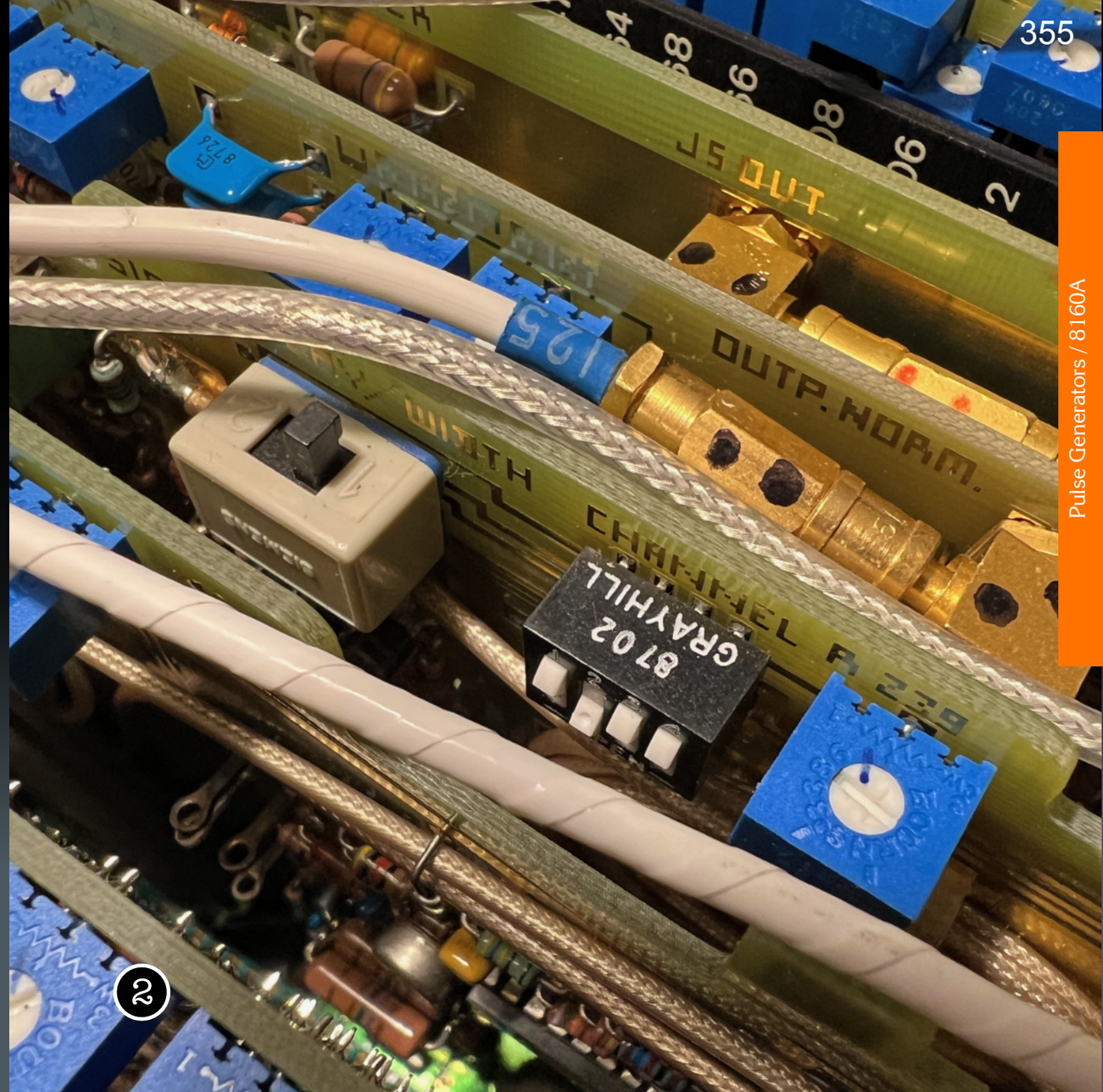
Interconnections

Most of the 8160A boards directly plug in the motherboard, from which they receive the logical signals.

The analog signals travel by mean of coax cables and beautiful RF gold plated connectors.

❶ Time Interval blocks physical interconnections.

❷ The switches which assign the role and the address to Time Interval blocks.



A Flexible Structure

The resulting structure is very flexible, and you can quickly reconfigure it for diagnostic purposes, either by physically moving the connectors like they were water pipes, either by reassigning roles and/or addresses simply flipping the switches on the Time Interval blocks.

Time Interval Blocks

Summarizing, the delay and width functions are obtained by using identical Time Interval blocks, a switch determining whether they operates as a delay generator or a width generator, or for which channel.

The TI block is mainly a delay generator (figure ❶ As mentioned, each block is composed by three boards:

- the first board (type A26) produces very short delays, from 0.1 to 9 ns;
- the second board (type A27) produces delays from 10 to 40 ns;
- the third board (type A28) produces delays of 50 ns or more.

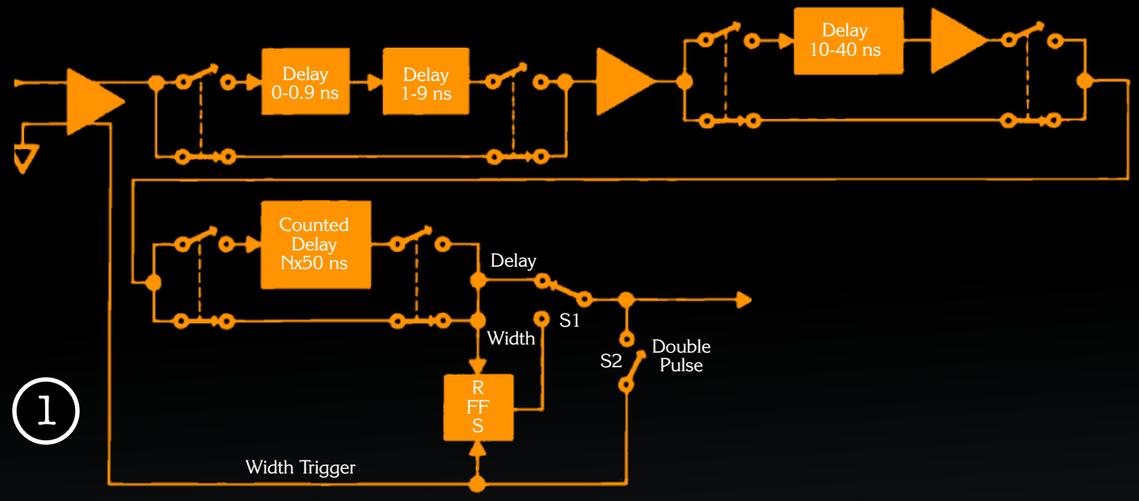
The **pulse width** function is obtained just adding a flip-flop to the delaying structure. This flip-flop is set by the trigger pulse originated by the period generator and reset by the delayed pulse.

Delaying Circuits

Very short delays (0.00 to 49.9 ns) are produced by switched delay lines, either printed-circuit board micro-strip line or sections of 50Ω coaxial cable. This approach gives ±1% accuracy and low jitter, and the delay time is not restricted by the repetition rate.

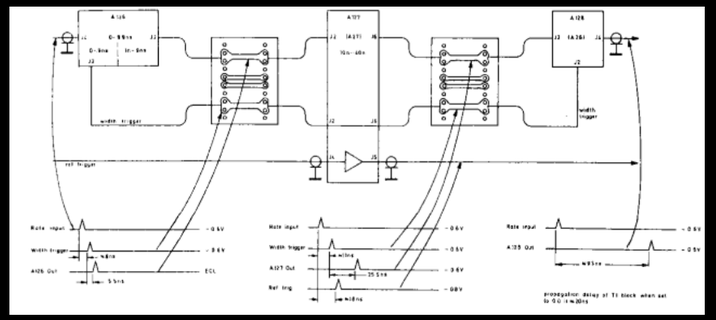
The **longer delays** are originated by using a digital circuit with a presettable counter. At the beginning of a delay interval, the counter is preloaded with an appropriate number and decremented until zero. The oscillator that generates the signal to the counter is not based on a crystal, as I could expect, but is an astable multivibrator that has a 25-ns delay line in a feedback path to give it a period of 50 ns. When the counter overflows, it produces the delayed pulse and stops the multivibrator.

With this arrangement, delays are generated with better than 1% accuracy and the jitter is less than 0.005% of delay for delays longer than 10 ps. This compares to the 0.1% jitter specification of earlier instruments.



More details

Here on the right, you can see a more detailed block diagram, obtained by trying to restore the one from the manual, adding some data about the delays generated by each board. It may be helpful when you need to repair a TI module, together with the following troubleshooting diagram from the manual.



Manuals

I could find the following manuals for the 8160A:

- 08060-90002, March 1979, applies to instruments with serial numbers 1804G00161 and higher;
- 08160-90005, 1987?, two volumes, applies to instruments with serial numbers 2811G00796 and higher.

They are rather different, and, if you need to work this old generator, maybe both are helpful. It seems that the former was written in Germany while the latter in the USA.

❶ The 3325A A6 board, where many new digital integrated circuits are widely spaced on a PCB with only two layers. Note how gold plated-PCBs were squandered without saving. This also was destined to change. ❷ A half of the microprocessor described in the text.

Boards Structure

Position-free?

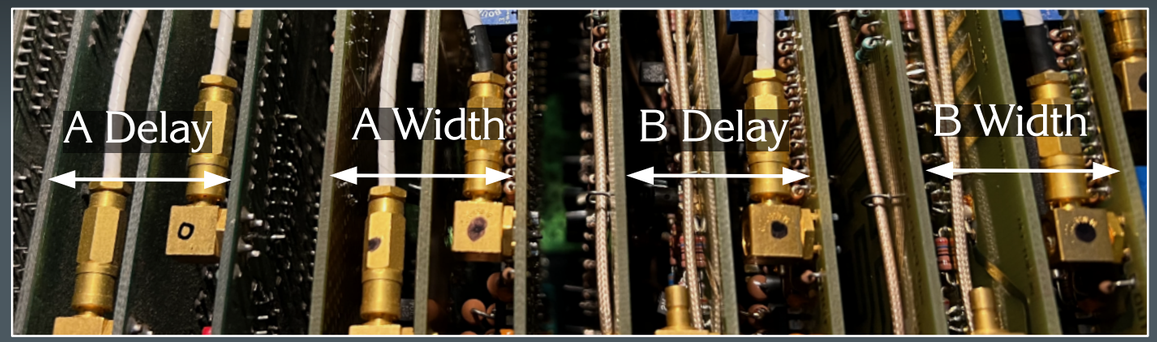
The housing's top cover shows board arrangements for both the standard model and that with Option 020. For what I could understand, boards can be placed almost in every position, but Time Interval blocks must not be separated and cannot be placed across the established position, because use some lines to interconnect each other. For example, board addressing is performed by A128 board and then passed to A126' and A127' latches.

I named the Time Interval boards as A126, A127 and A128, meaning with them the model type, but when inserted on the bus their ID changes adding "100" for each group, so, e.g., channel B Width Time Interval block is numbered A426, A427 and A428.

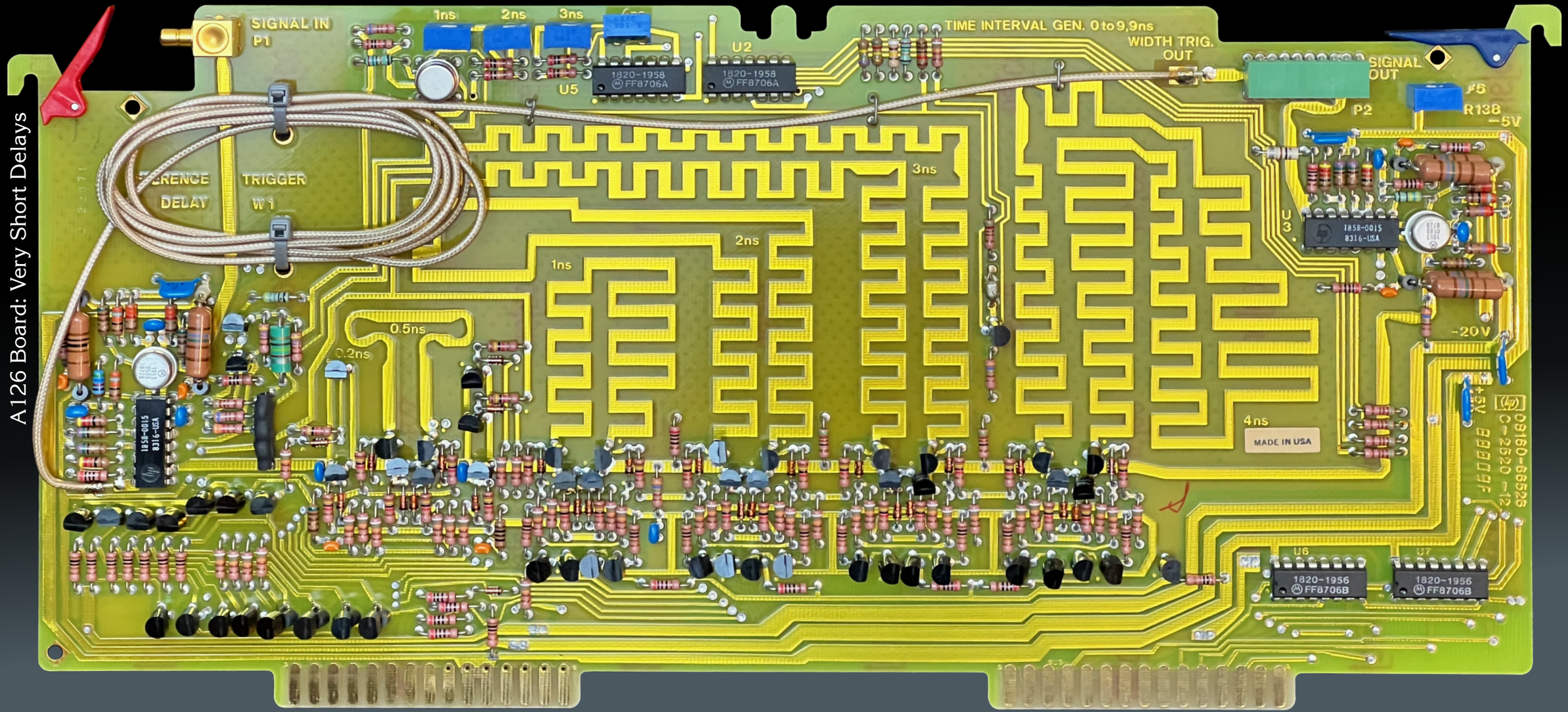
Why to do that?

You could think that this is just a lucubration of mine; just set the board where they belong and don't bother us… On the contrary, it can be useful to remove the central boards and put the boards under test on the right, to have room to access them with the scope probe. With some smart adjustment, you can in some way survive even without dedicated board extenders.

❶ The cover internal showing board arrangements for both base model or Option 020
❷ Time Interval blocks in my 8160A; each of them is composed by three boards. Each block is identical to the others and distinguishes only by switches settings, so that in theory yours could have a different arrangement.

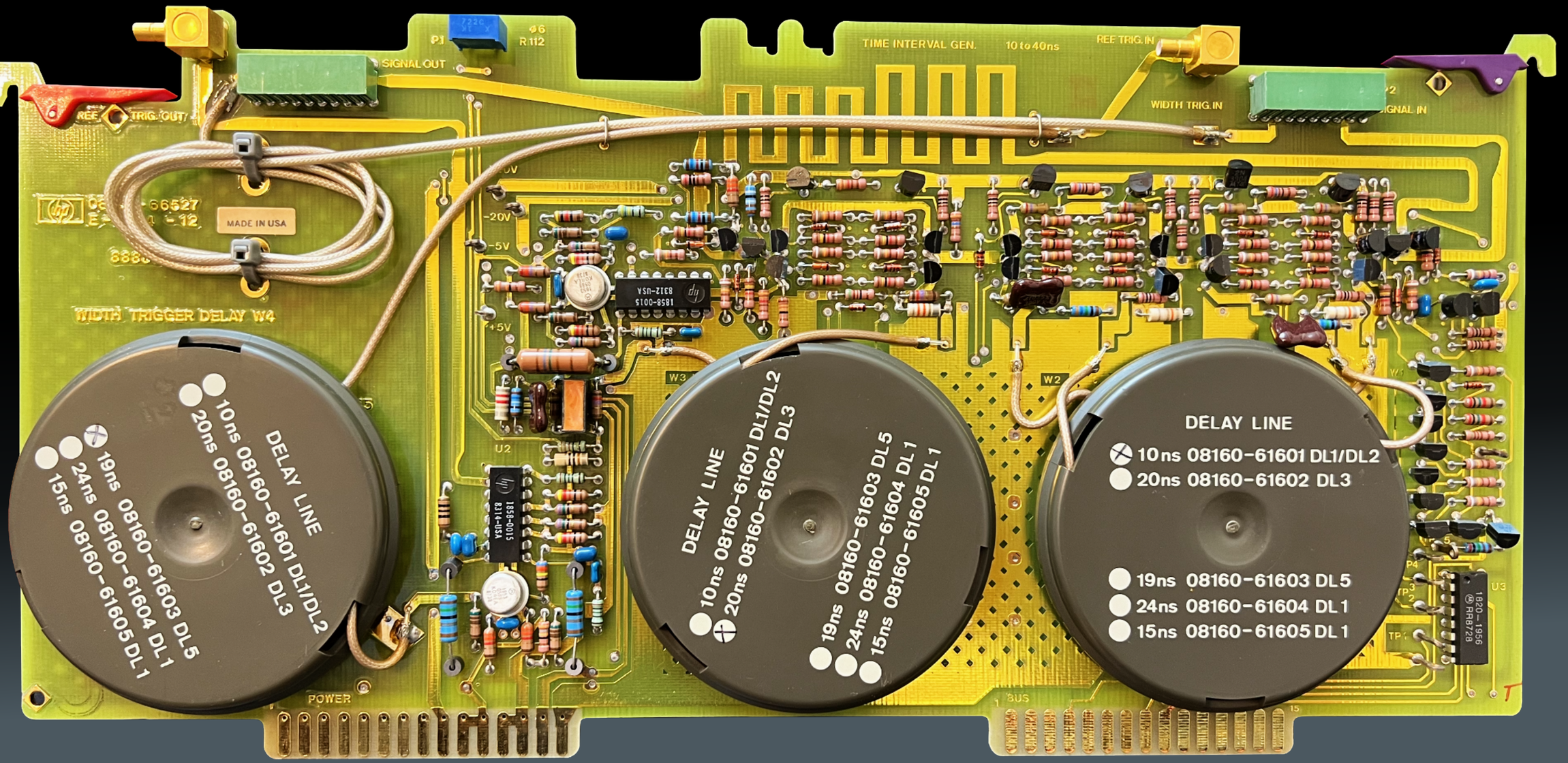


A126 Board: Very Short Delays



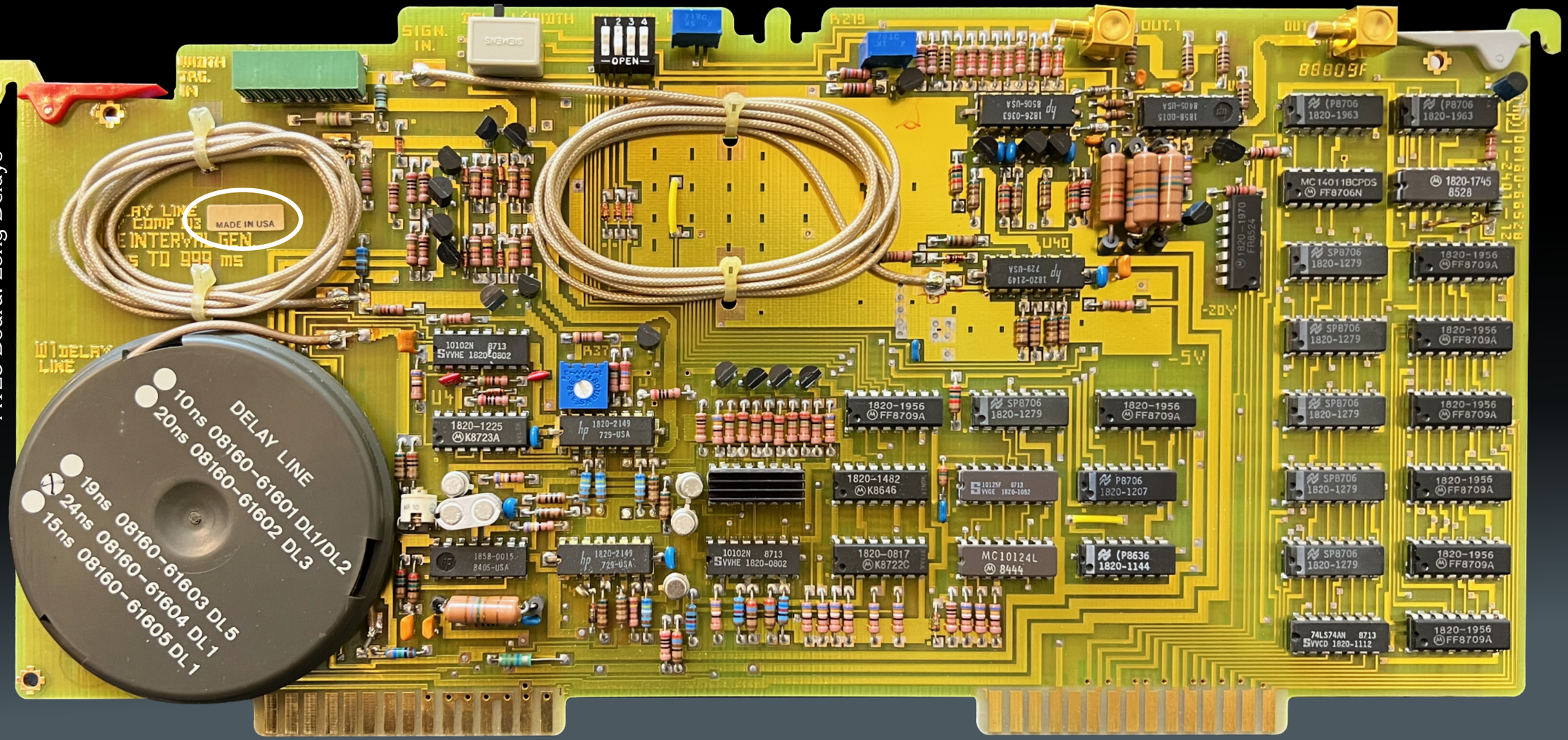
I find exceptionally beautiful this board, with the delay lines directly printed on the circuit board. Although they seemed to me very stable, they changes their characteristics with the temperature, and a special circuit is provided as a compensation.

A127 Board: Short Delays



Here, delay lines become bigger, as expected, and are implemented with coaxial cable (one on the PCB is however still present).

A128 Board: Long Delays



This board has still coaxial cable delay lines but includes a full digital section. The smaller delay lines (50 ns) are used for the multivibrator that produces the clock for the digital section. According HP this solution ensures a very low jitter. Note that this board, like the yellow others, has been built in the USA.

Repairing A126 Board

Luck

Luckily, my 8160A arrived with Option 020. That means that I had a double endowment of A126-A127-A128 boards, and I could then check them all. All of them were OK, except two, both of A126 type.

The (German?) manual 08060-90002, March 1979 reports waveforms and voltages, so I could find rather easily the broken chips, both 1858-0015, but in different positions, U1 on one board, U3 on the other.

Incomprehensibly, those precious information has been removed from the newer (USA?) edition 08160-90005, 1987.

Bad Luck

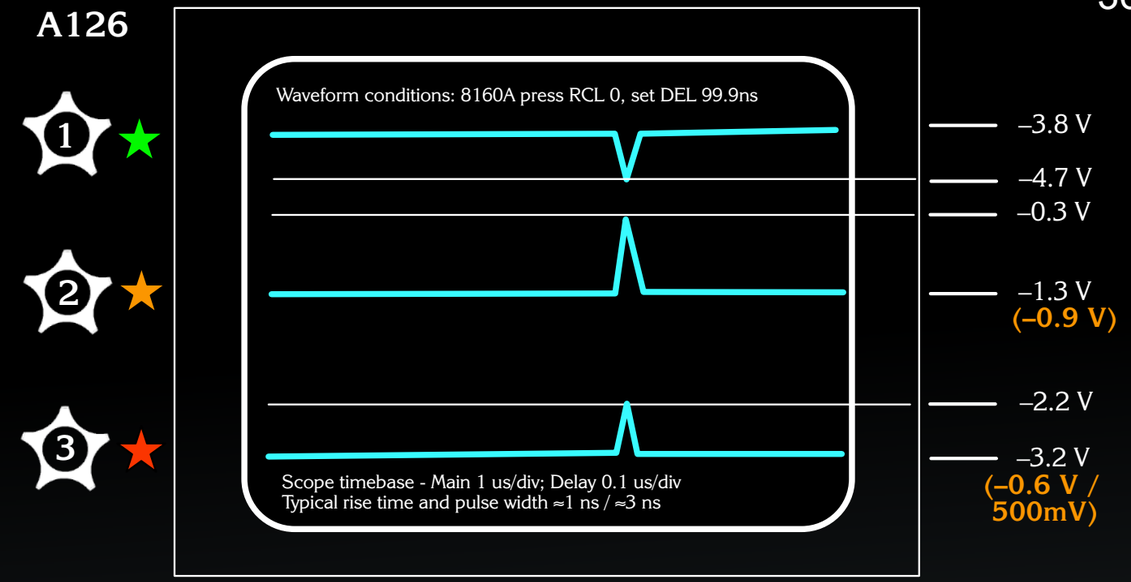
Unfortunately, this part of the older manual was nearly not readable, so I had to restore the images and acquire again them from the good A126 board I had.

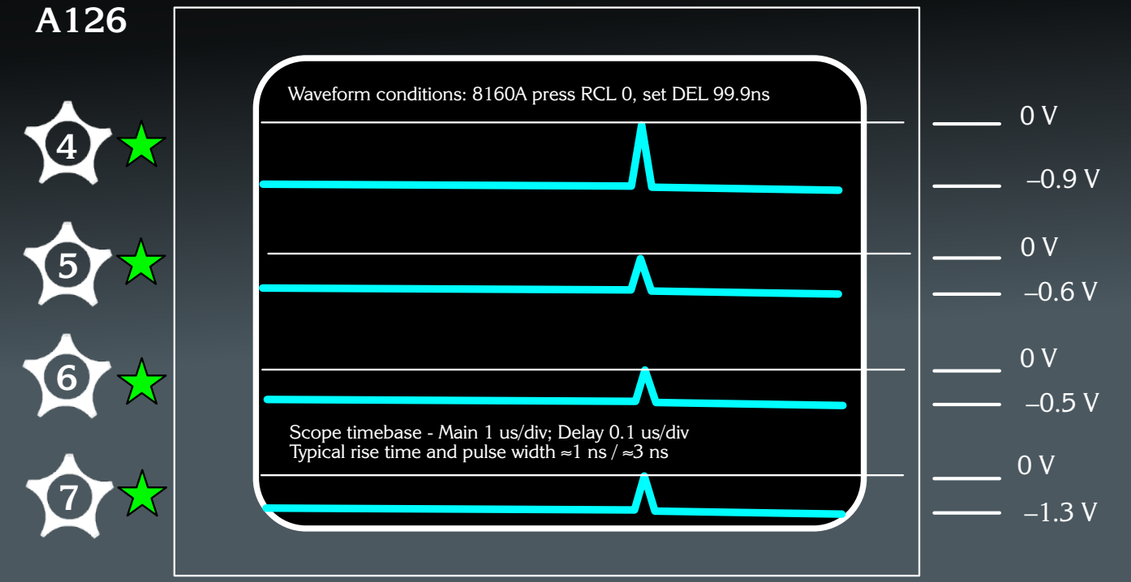
To get the waveforms, use the 8160A TRIG OUTPUT output to externally trigger your scope, and press RCL 0 to recall the standard setup of the instrument, followed by DLY 99.9 NS.

In the figures, I marked the traces with colored stars to mean the grade of accordance of my waveforms with the manual and I indicated the read values where different.

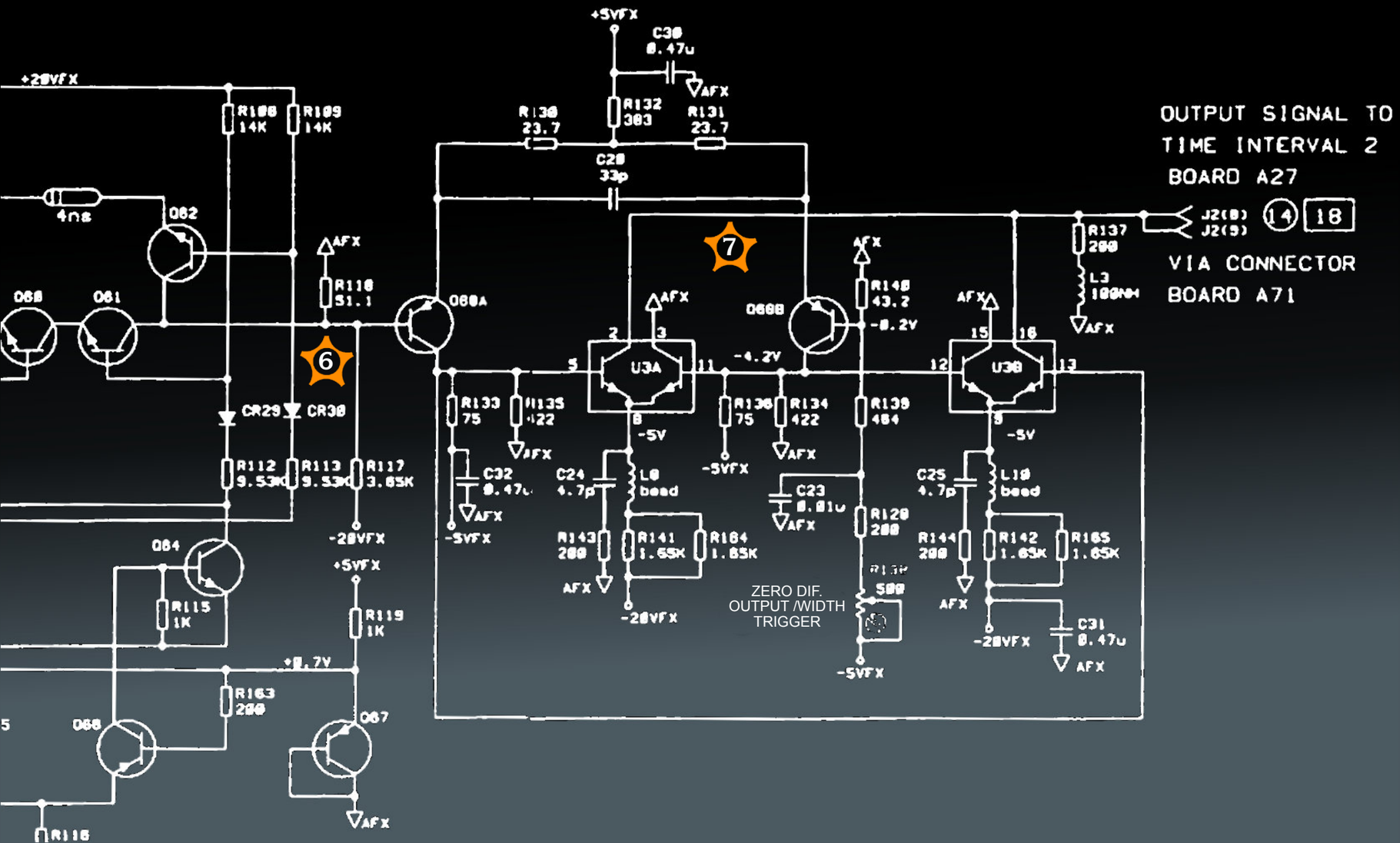
Note how the 8160A uses very short pulses instead of common TTL levels; I believe to better exploit delay lines. To see them you need a good scope and a good probe. The difference is very evident.

Facing page: the “restored” waveforms from the 08060-90002 manual which is almost unreadable. Green, orange and red stars indicate if I found them in accordance with the manual or less.





The Circuit



The Places of Crime

Here you can see one of the circuits where the transistor we talked about was killed.

Even if with different purposes, the two failing circuits are very similar if not identical. Here you can see the output circuit of the A126 board. The other, is on the A126 board input.

According my opinion, the circuit consists of a PNP differential amplifier (Q68A/Q68B), where Q68B base is held at the reference voltage, followed by an NPN differential amplifier (U3A) producing the output signal, probably as current source.

The second section of U3 (U3B) is used in this case just in parallel to the A section, to increase its driving capability.

In the other circuit, on the A126 board input, the two sections are used for different purposes: the current source output U1A goes to the Delay function and the current source output U1B goes to the Width function.

Fault type

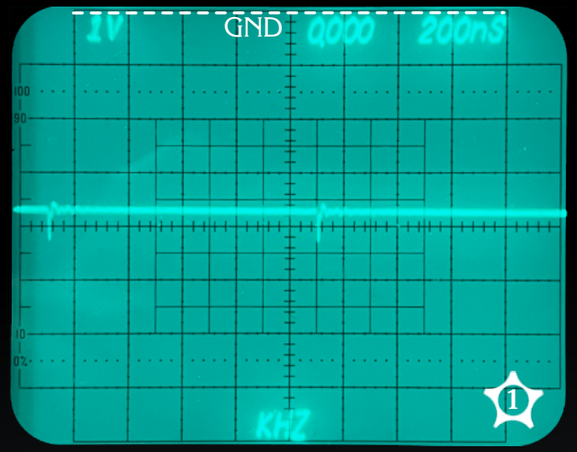
In both the faulty transistor of U1/U3, the 5-2 junction was broken. One of them was completely open, the other pretended to work with the Chinese transistor tester, but did not pass the VOM test.

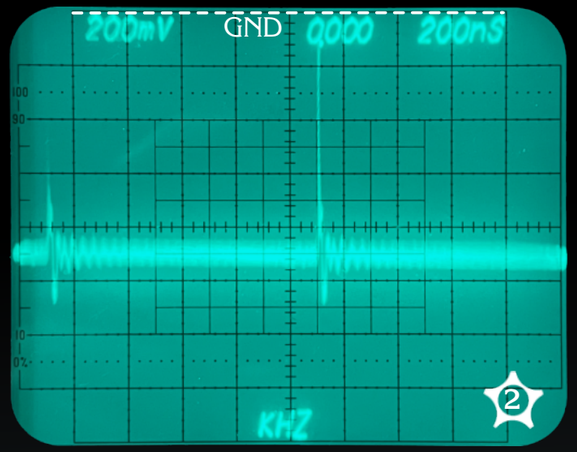
An inexpensive S9018 external transistor is now playing their role in a good manner, it seems.

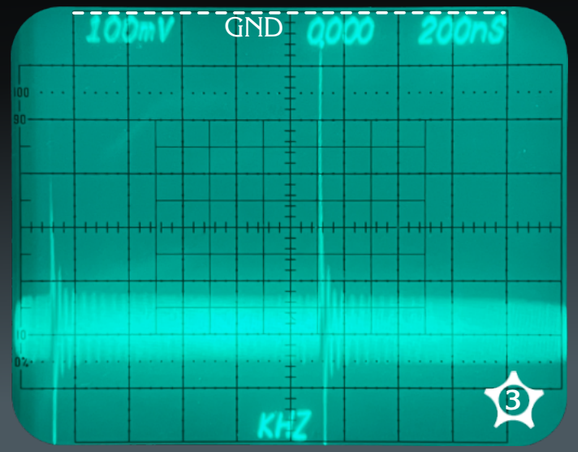
The S9018 is designed to be used as AM/FM Amplifier or Local Oscillator of FM/VHF Tuner, with High Current Gain Bandwidth Product ft=1.1 GHz.

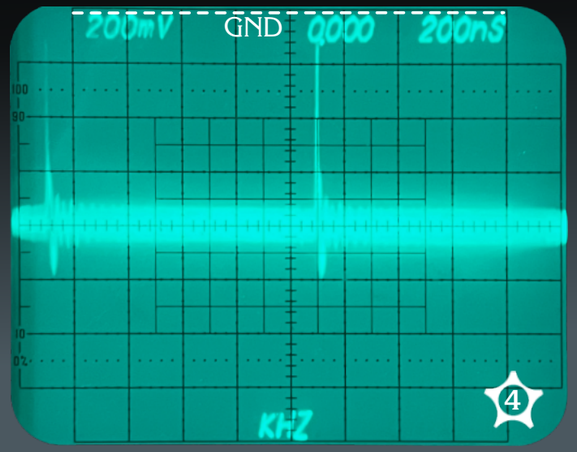
Waveforms

A126 Board Test Point Waveforms

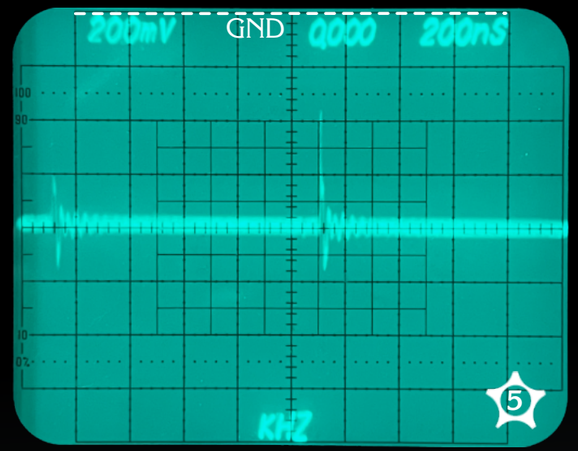


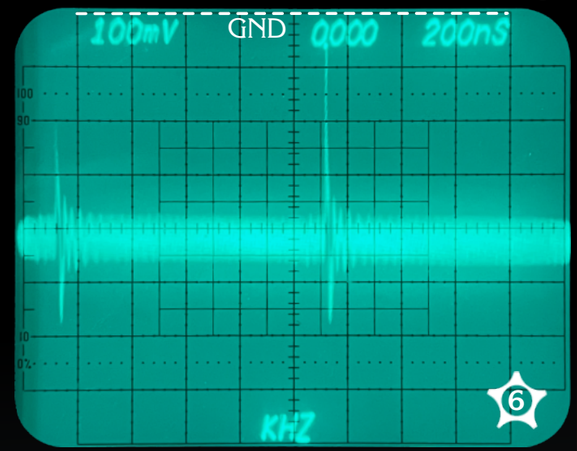


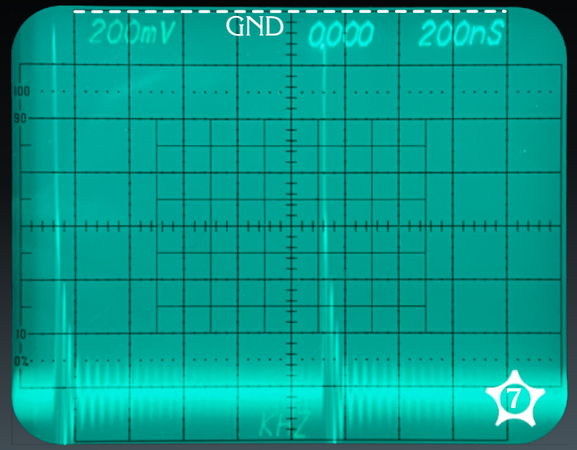




All the above waveforms have been taken with a Tektronix 7623A Scope using its CRT storage capability, either to make more visible the narrow pulses, either because I have only two hands and needed one to hold the probe, while shooting the photo... The 7623A is still today a wonderful oscilloscope, often better than a DSO.

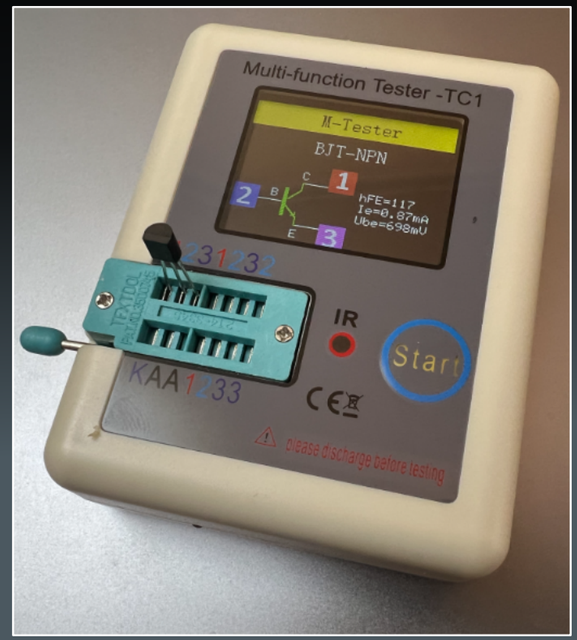






A small tool

You can buy it on Amazon for few euros and allows to test transistors, FETS, diodes but also capacitors and inductors. It is not always infallible; in this case, it told me that a transistor was good but it was not. If you have not a curve tracer, a test with the VOM is also recommended.



Poor Man's Repair

Determining the Fault

I already told you who the murder is. Once understood the circuit, determining the cause of the missing output was not too difficult. Thanks to the supplied waveforms, and helped by having working boards, it was relatively easy for me to understand the possible faulty areas, where just two breakable component were presents: a double PNP transistor in a single can and a 4-transistor array in DIP-16 package.

I started with the double transistors; I carefully desoldered them and tested with both the VOM and a small Chinese device that I bought for this purpose (see the photo on the previous page). Both said that they were good.

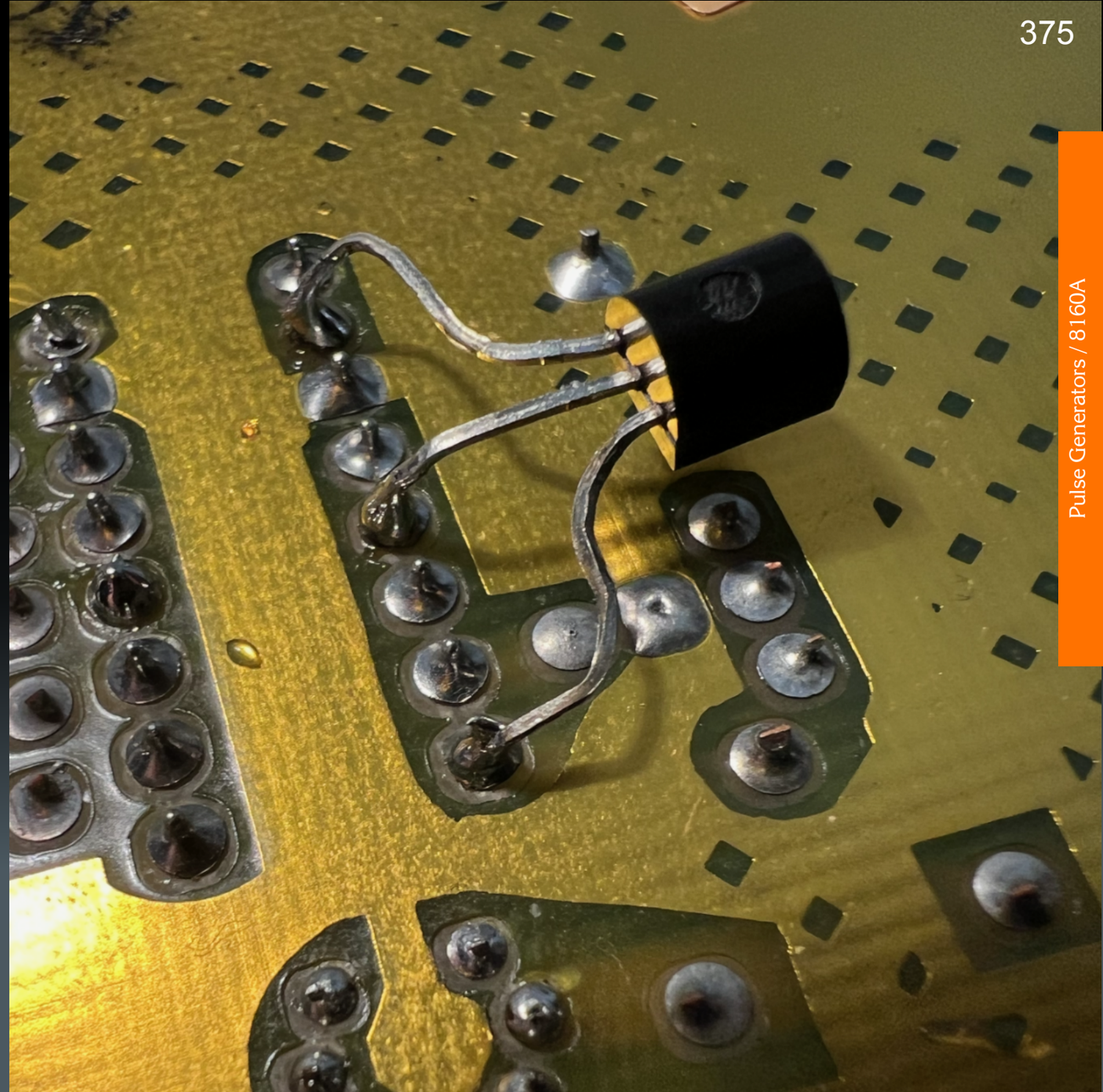
All the voltages except the outputs were right, so the only possible way was to unsolder at least one of the transistor arrays, using the hand pump, the only I have for this purpose; a job I don't like so much.

According to the transistor tester, this also was OK, but the VOM said that a base-collector junction was broken. I had no other way than dismounting another array. In this case the VOM and the transistor tester agreed, telling that one of the transistors in the array was broken. Rather funny: the same transistor in two different arrays used in different position on different boards (I repeat, U1 and U3 on two different A126 boards).

I had to bite the bullet, and removed the two other (presumably good) arrays U1-U3 from the two A126 boards, for a total of four 16-pin IC. I placed four sockets in their places and separately tested both the boards with the good arrays. Both boards worked perfectly.

Spare parts

You think I finished, but I needed two new 1858-0015 Hewlett Packard ICs, and they are not easy to find. I could find just one, but the ransom was at more of 50 euros, shipment included, definitely too much. Another option was a set of untested replacement boards at 170 euros, maybe a right price, but too much for me. So I decided to try to replace just the broken transistor. I cut the pin to the faulty IC and added a new S9018 transistor from outside, the only RF I had, as shown in the photo. I had very few hopes, but, incredibly, both worked. In the end they only operate switching.



More to Fix?

The Problem

I observed that the increment/decrement of the various parameter was not linear. The sequence was that typical of when a bit is missing. It was correct until a certain point, then the value remained the same and then started again to move. For example, 50, 49, 45, 45, 45, 45, 44… instead of 50, 49, 48, 47, 46, 45, 44…

The problem was not new, but others had it on a board only (e.g. WIDTH), while I had it on **all** the boards in the same exact way.

Usual Suspects

Considered that peripheral addressing was substantially a rather simple multiplexed data/address bus, generated by mean of microprocessor ports, I thought that some driver or receiver had some shorted pins. But was it the driver, or one of the receivers? (which they call in "**acceptors**")

Catastrophe?

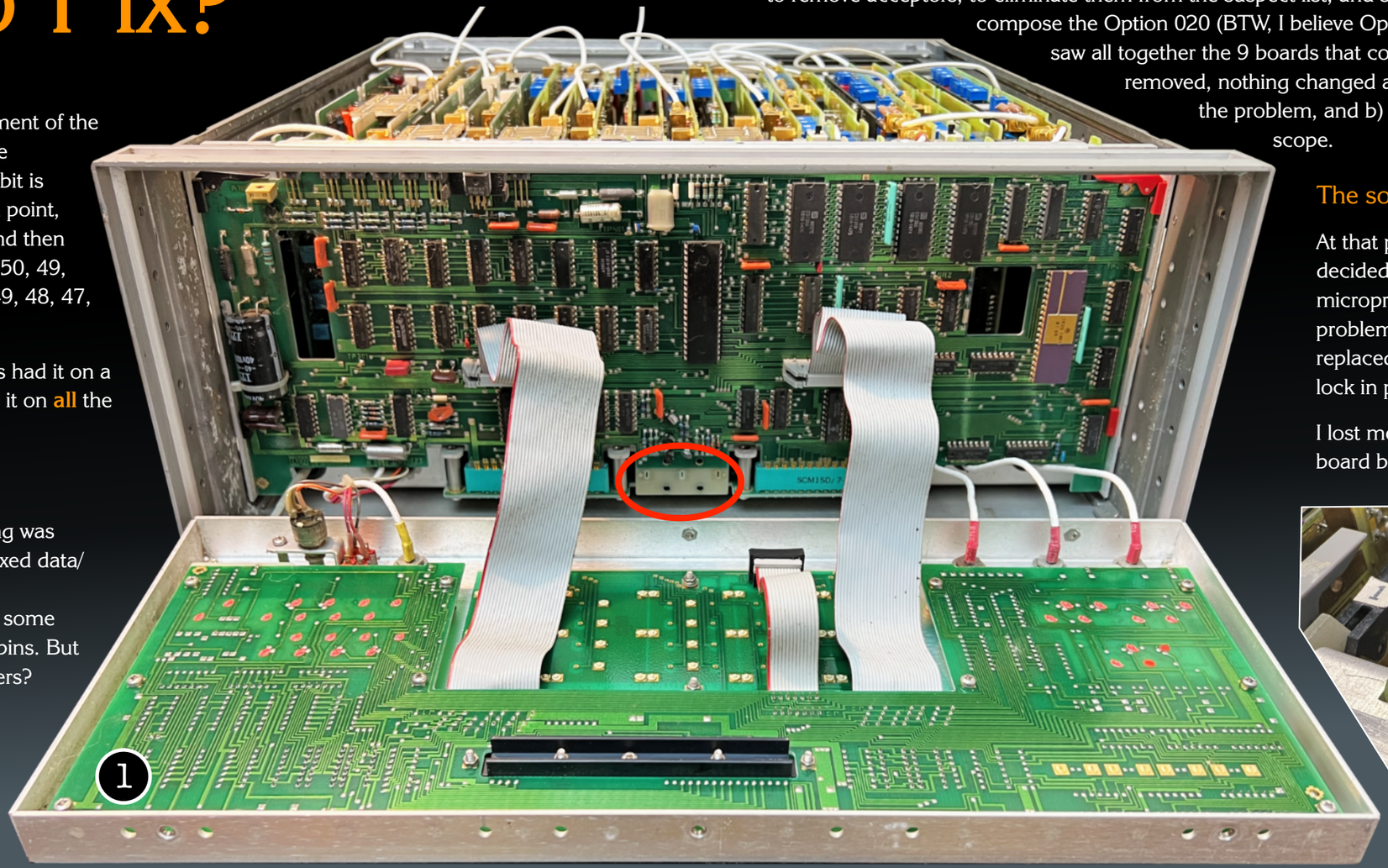
While testing, the catastrophe: nothing worked anymore, it seemed that the uP could not access the peripherals any longer. I mentally searched for possible problems, but no, I didn't make mistakes, the fault was spontaneous.

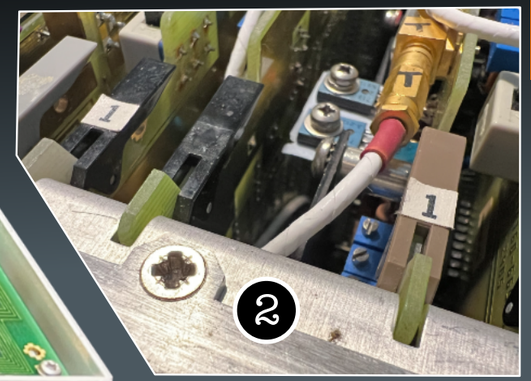
I thought that the half broken driver went to bankrupt and stopped working at all. It was easier starting to remove acceptors, to eliminate them from the suspect list, and so I removed all the boards that compose the Option 020 (BTW, I believe Option 020 was so expensive, when I saw all together the 9 boards that compose it!). But with the 9 boards removed, nothing changed and I decided a) to better analyze the problem, and b) to analyze the peripheral bus with a scope.

The solution

At that point I had a good inspiration, and decided to extract/insert more times the A2 microprocessor board. That fixed the problem. To be more sure of the result, I replaced the two missing screws which lock in place the A2 board (photo ❷).

I lost more time reinstalling the various board but now the fix seems to be OK.





❶ The 8160A's A2 microprocessor board can be easily serviced just tilting down the front panel. Good HP engineering… In the circle the original location of the RAM batteries. I suggest to move them to a safer location to protect the board against possible acid leaks. ❷ One of the two screws which keep in place the A2 Microprocessor Board.

Alphanumeric Displays

Still a novelty

These of 1978 were the days in which alphanumeric displays were still a novelty, a luxury novelty, and were used sparingly. Their presence in the 8160A indicates how ambitious its project was (the other generators used seven-segment displays and LEDs as indicators). At the time, we still used teletypes to talk with our microcomputers, and LCDs were far to arrive.

Replacing Them?

More types are used:

- DS1, DS2 and DS3 (“PER”, WID” etc.): 1990-1205
- DS4 (CHANNEL): 1990-0651
- DS5, DS6, DS7 and DS8 (value): 1990-0507
- DS9 and DS10 (measurement units, eg. “ms”): 1990-1205.

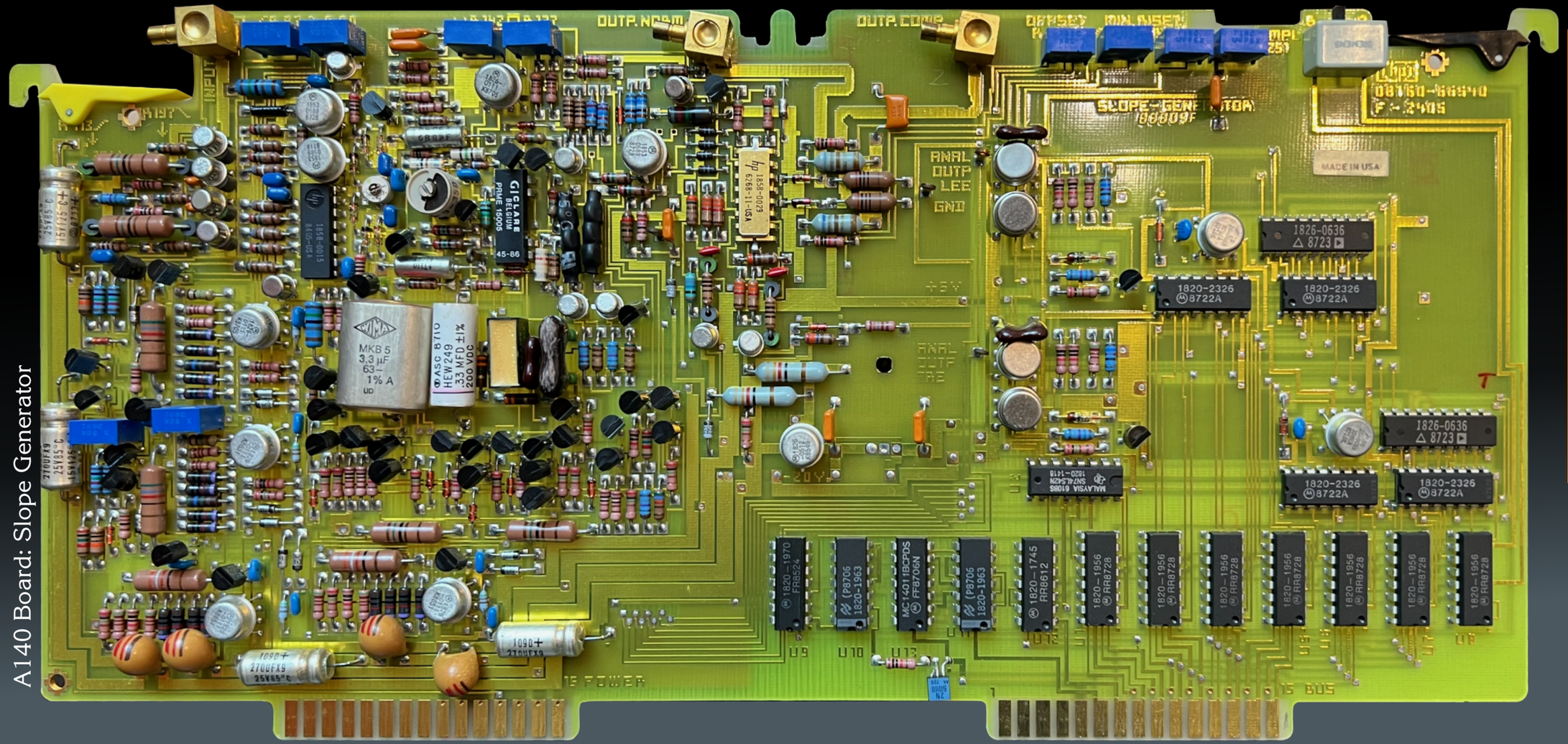
Unfortunately, it seems that there is not too much on the Internet about them. The 1990-1205 is totally unknown to the net, while the the 0651 can be found on eBay at only …85 USD each! The 0651 seems to be available, but you must request a quote for it.

In other words: you’d better keep them with care…

Photo: the three 1990-1205 alphanumeric displays indicating the PARAMETER currently under modification, by mean of the keyboard or the active verniers.

Photo Parade

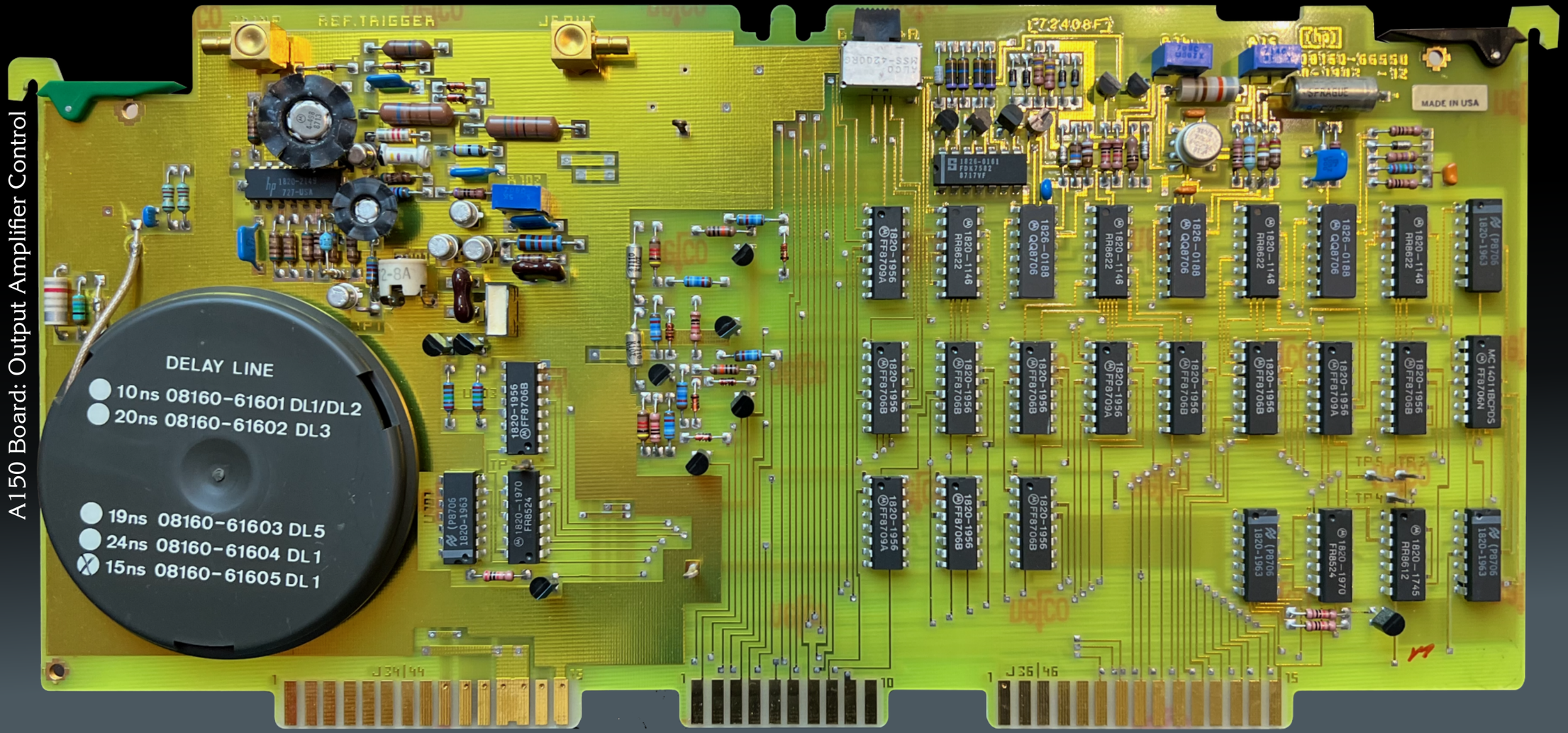
A140 Board: Slope Generator



I took the opportunity, as usual, to take some photos of the boards I needed to remove from the mainframe, should they be useful to someone else in the future, or just to look.

I find this board wonderful. Note 1% capacitors in the middle of the left section. It works splendidly and allows you a micrometrical control of the leading and trailing edges of the pulse. Each channel has independent controls, like any other parameter, excepts period.

A150 Board: Output Amplifier Control

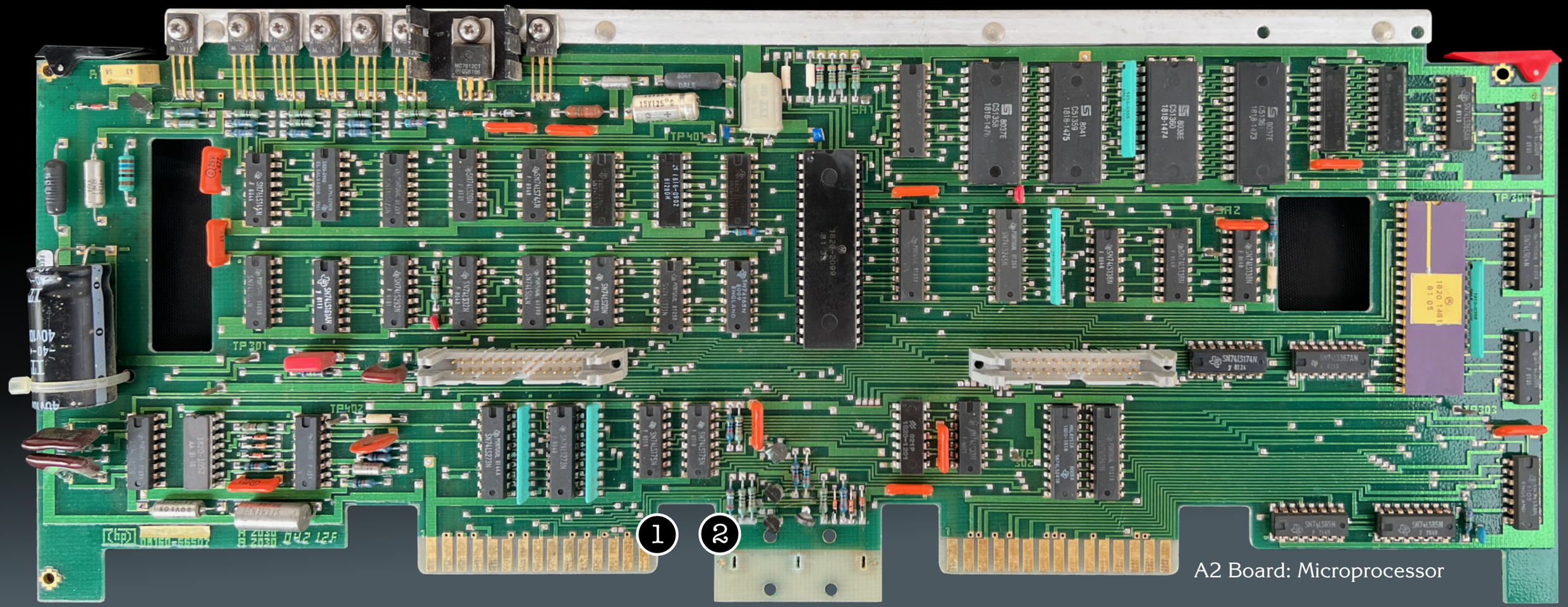


This board controls the output power amplifier by mean of the signals passed to it via the central edge connector. A delay line cannot be denied to anyone... They are big and space-waster but work very well.

A151 Board: Output Amplifier



Output amplifier, with its large heatsink. It must supply up to 10V on a 50Ω load.



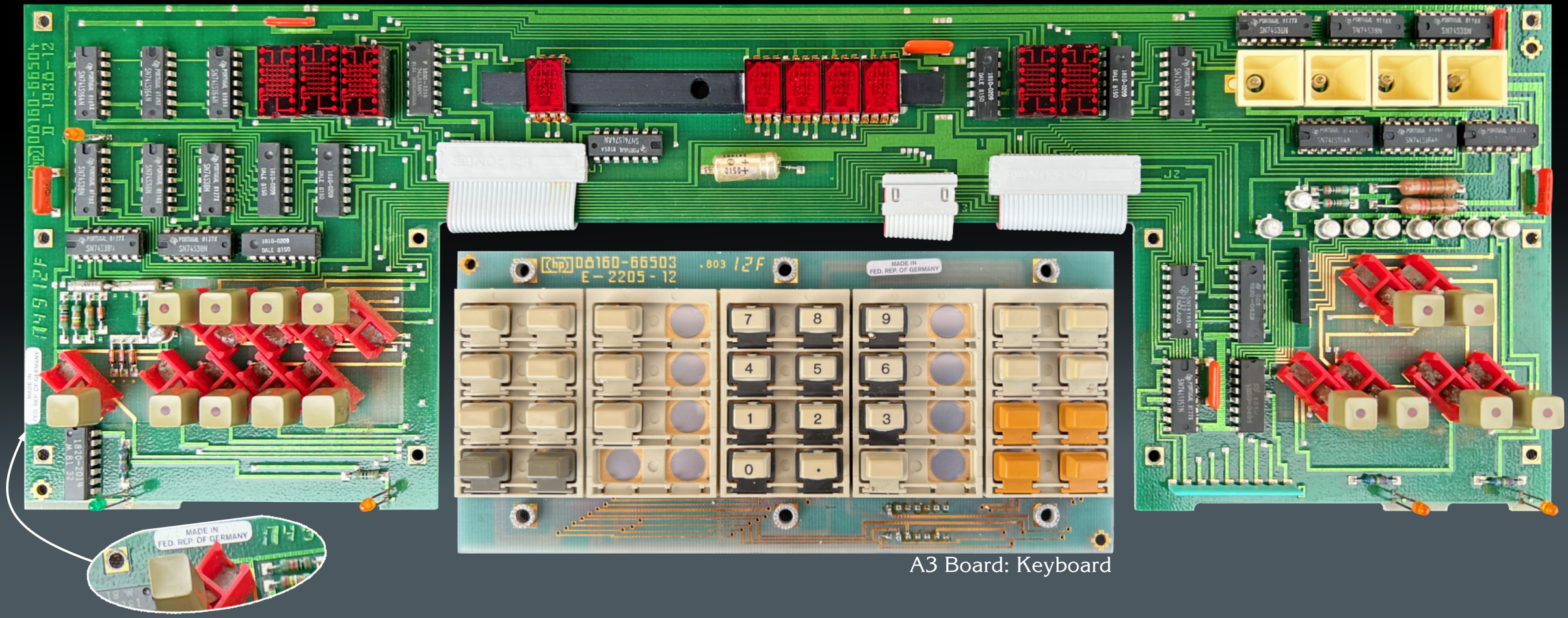
❶ The 3325A A6 board, where many new digital integrated circuits are widely spaced on a PCB with only two layers. Note how gold plated-PCBs were squandered without saving. This also was destined to change. ❷ A half of the microprocessor described in the text.

Display & Keyboard

Note how similar are these boards compared with the 3325A. The detail shows that this board has been produced in Germany, while the ICs say that it was built probably in middle 1981. Many other boards were produced in the USA and were from 1987.

For cleaning the keyboard contacts, I recommend as usual the very good WD40 Contact (never use WD40 standard!). Its effects are miraculous.

A4 Board: Display



A3 Board: Keyboard



Another Opinion

Another Mad Collector with Another 8160A

Two-channel 50 MHz pulse generator, designed by HP-Germany but built in the USA (*Gianni's note: not completely true: some of my boards are built in Germany*). Unlike most (vintage) pulse generators that have analog knobs, this unit is programmed all digitally from the numeric front panel keypad. Simply punch in the period, width, delay, leading and trailing edge times and high and low amplitudes and you are good to go. Has the usual external gate and trigger functions and will also do double pulses. Selectable output impedances of 50 and 1000 ohms, similar to that found in the HP 8165A; however, the effect on output voltage of the output impedance is not what you would think since this thing is designed basically as a current source. HP also sold this in a single channel variant (less Option 020), but my $50 eBay purchase luckily was the two-channel version. HP also made the HP 8161A which has slightly better rise/fall times than the 6 ns I am getting. The basic accuracy for most parameters is about +/-1%. One of the nicest features is that it will add the two channels together with a flick of a button. By varying the pulse delay parameters, one can then come up with a slew of interesting three step waveforms. The big surprise is when you take off the top cover and peer inside. Staring at you are 23 circuit boards, spaced about 1/4" apart with absolutely no free space anywhere to be found in the chassis. I have numerous other pulse generators and they all have a couple of boards at best. So why does the 8160A need 23 boards and why is it rated at 675VA? And why did it cost $25,000 in 1992? Ask the Germans.

(from beautiful https://emperoroftestequipment.weebly.com, where you can find also the repair story. BTW: it describes also a problem like mine - see "More to Fix", but just on one board).

In the photo: what can be the history of my 8160A? It joins many new boards, shining like new, with 6 old ones, dirty with dust and clearly from a different production line. I would expect the opposite: many old boards with some replaced. It seems that the mainframe and the green boards are from 1981 and were built in Germany, the newer boards are from 1987 and were built in the USA.

Conclusions

Love Stories

So, like in a love movie, the initial dislike turned out into a great passion. This was due mainly to my low level of knowledge, in general, and about HP instruments, in particular, which only today I try to understand and analyze. But, after the 8165A, the 8012B and, above all, the 8015A, my distrust had some good justifications. Definitely, HP had product lines for rich and less-rich customers.

Technical Solutions

It was very interesting for me to discover some exclusive 8160A technical solutions, like the extensive use of delay lines, or the insulated power supply for the output amplifier. If with the 8015A I had a creeping thought that my TTL home-brew pulse generator of the seventies could eventually be better than a delicate balance of transistors, in front of the magic 8160A you can only sit down and learn.

A Great Classic

The 8160A, despite my former suspicions, entered thus my personal top list of **timeless great classics**, together with devices like the **8568B** Spectrum Analyzer and the **8640B** Signal Generator at HP's, or the **545**, the **7854** and the **7934** at Tektronix'. The Option 020 added much more than a cherry on the cake; it is like a second generator, but integrated in the first one, capable of multiplying its already numerous possibilities. I can suppose that, still currently, there is few equipment capable to control produced pulses down to one nanosecond at a time, a problem that probably only who must precisely qualify a device has to solve; for most of us and our applications, such precision is not always required, and a 8015A is enough. But for a silly collector like me, the 8160A is invaluable.

In the photo: some of my everyday work's friends: the 7623A and 7633 CRT Storage oscilloscopes (I find using two very practical), the 5316B Universal Counter, and the 3403C True RMS voltmeter. Very useful also the 7000-Series modular architecture. Here we have the 7D13 multimeter plug-in, which in DC is at least as accurate as the 3403C, and the 7D14 Frequency Counter. Not shown, but priceless, the 7A13 differential vertical amplifier.

Besides the 3325A Function Generator (another wonder), the often referred 8012B Pulse Generator, and the "jewel" 321A portable oscilloscope, barely visible are portions of the top-technology GRC-19 short wave "tube-digital" receiver-transmitter (below) and, above, the portable 465, the tube-based 310A and 515A, and the HP400H tube voltmeter, as well a high precision instrument of the fifties. Not shown but frequently used, the 2431L DSO and the analog 2445B with digital counter option. In some of my books you find the description of them all.

Signal Sources

Subsection
3325A Function Generator

Wonderful and new (then…)



1979

3325A Function Generator

What it is

Hewlett-Packard defined the **3325A Synthesizer/Function Generator** as four things in one box:

- an uncompromising, high performance **synthesizer** with 11 digit resolution;
- a **function generator** with precision waveforms;
- a wideband **sweeper**;
- a **fully programmable** systems instrument.

It was due

Judging from the general catalog, in 1977, HP's offer for signal generators was extremely rich. Their number and variety make not always easy to classify them, but in general, many call **Function Generators** those capable of producing sine, square, triangle and ramp signals. Among these, most HP models where still analog, perhaps getting less suitable for a world more and more digital.

In 1978 catalog, defined as **Programmable Signal Source**, a new product was introduced: the **8165A**, PLL locked, from 1 mHz to 50 MHz, with sine, ramp and pulse waveform, counted bursts, 20 Vpp and fully programmable, but its $6,000 price did not positioned this starship as a possible competitor of the older models.

3325A's Arrival

Increasingly stringent requirements

At the end of the seventies, measurement needs were placing increasingly stringent requirements on signal sources for greater frequency resolution and stability. Narrowband component testing, satellite and terrestrial communications, local oscillator and automatic test systems, personal computers and their peripherals were only a few of the many applications that continually required better and better signal sources.

Increased amplitude accuracy and resolution were also must requirements in many applications. The telecommunication industry's Frequency Division Multiplex (FDM) systems required high amplitude accuracy and resolution (0.01 dB) as well as high frequency resolution and stability. These requirements were also finding their place in many R & D and production test situations.

The arrival of the new 3325A

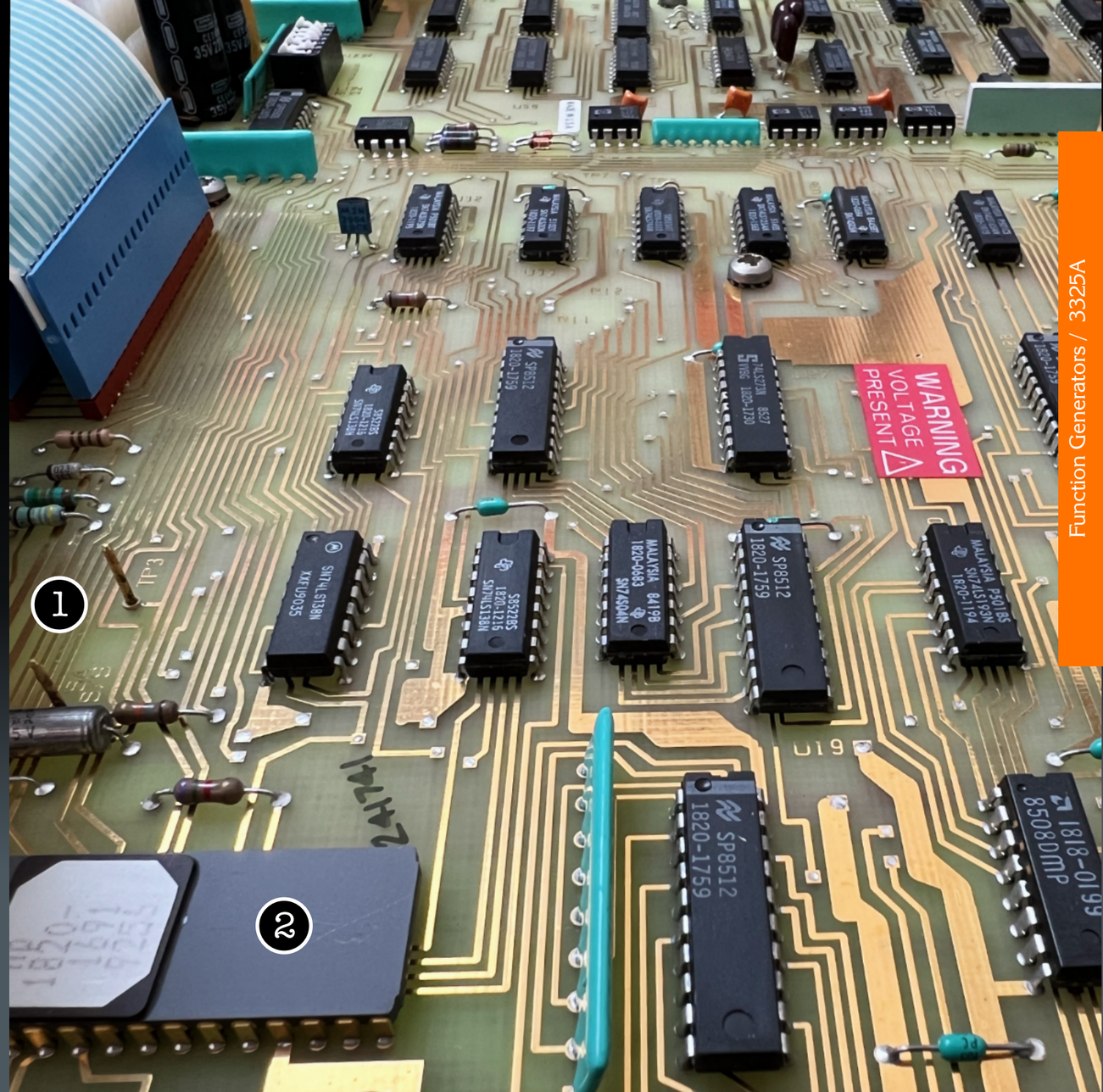
In 1979, the instrument that the market was waiting for finally arrived, at half of the 8165A price, thanks to new technology cost reductions in synthesis techniques. The new **3325A Synthesizer/ Function Generator** was an uncompromising, high performance synthesizer with 11-digit resolution, a function generator with precision waveforms, a wideband sweeper, and was fully programmable.

When introduced, the 3325A costed exactly $3,000, i.e., about 13,000 today, and thus it can be however classified among rather expensive laboratory instruments. Still today, is priced at €500-800.

Lightweight!

Used to apparently similar-looking devices (think the 8568B Spectrum Analyzer, for example), besides performance, what strikes you the most is weight. The heavy aluminum die casts have been replaced by modern digital ICs, and the stability is obtained by design in the circuit, not by mean of mechanical precision. The designers even allowed themselves the luxury of wasting space, as confirmed by the photo on the right. Soon the instruments will switch to new, smaller form factors.

❶ The 3325A A6 board, where many new digital integrated circuits are widely spaced on a PCB with only two layers. Note how gold plated-PCBs were squandered without saving. This also was destined to change. ❷ A half of the microprocessor described in the text.

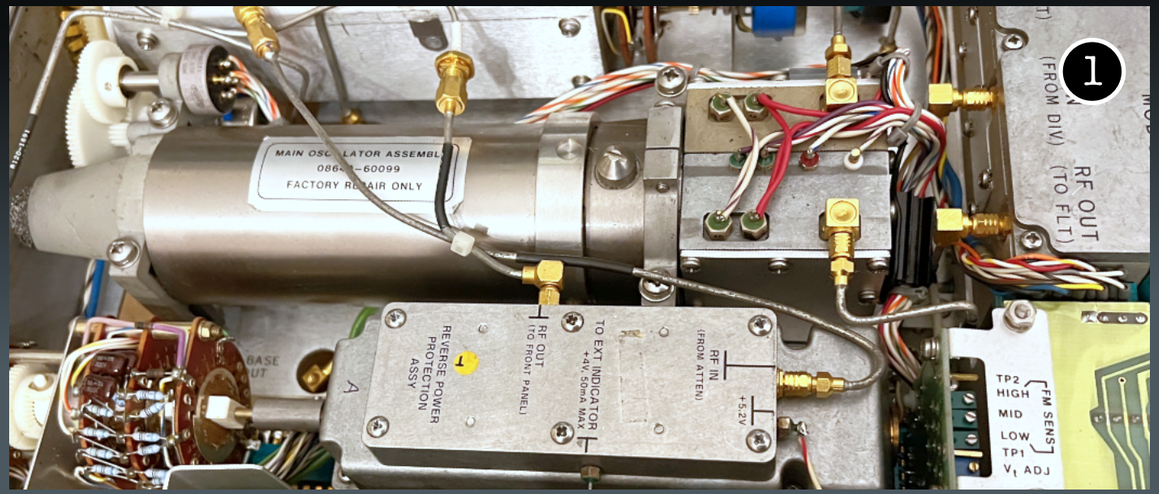


Synthesizers

The main dish in 3325A menu was certainly is its **frequency synthesizer**, an appetizing novelty in those years: an electronic circuit that generates a range of frequencies from a single reference frequency.

Prior to widespread use of synthesizers, most electronic devices relied on manual tuning of local oscillators, which used a resonant circuit composed of an inductor and capacitor to determine the frequency. That was generally not very stable, and variations in temperature and aging of components caused frequency drift. In some cases, like in the previously described **8015A & family**, the timing was obtained by mean of constant current sources discharging a capacitor, but, also in this case, the frequency stability was not exceptional.

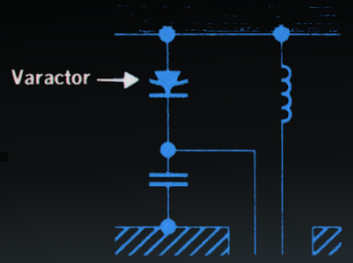
An intermediate solution was to lock a traditional free oscillator to a very stable reference oscillator with a **Phase Locked Loop**, as in the 8640B generator (as well described in this book), but it was not so practical and looked however as an afterthought; not every possible frequency could be locked, and a heavy construction was mandatory as well (photo on the right shows the resonant cavity of its oscillator).



On the contrary, in a frequency synthesizer, every possible frequency has the stability of the reference, and resulted to be the ultimate and definitive solution, as proved by the subsequent evolution.

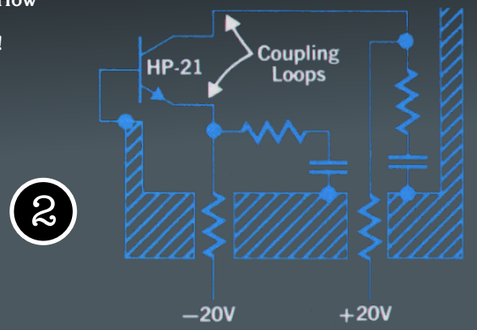
Fractional-N frequency generation

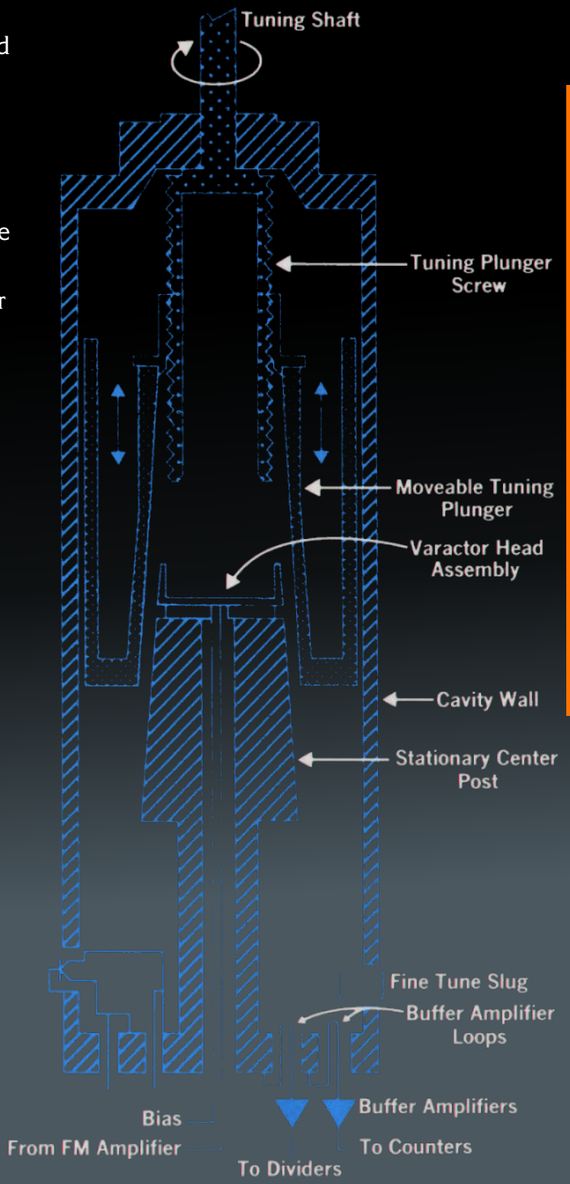
HP's 3325A, like the coeval 3335A synthesizers used the then new fractional-N technique, which we will analyze rather deeply later, which offered many benefits, like, for example, a lower phase noise. The 3325A represented therefore the state of the art in those years.



❶ The cavity is the heart of the extraordinary 8640B signal generator. A masterpiece in mechanics and electronics.

❷ The internal of the cavity. How much of technology!



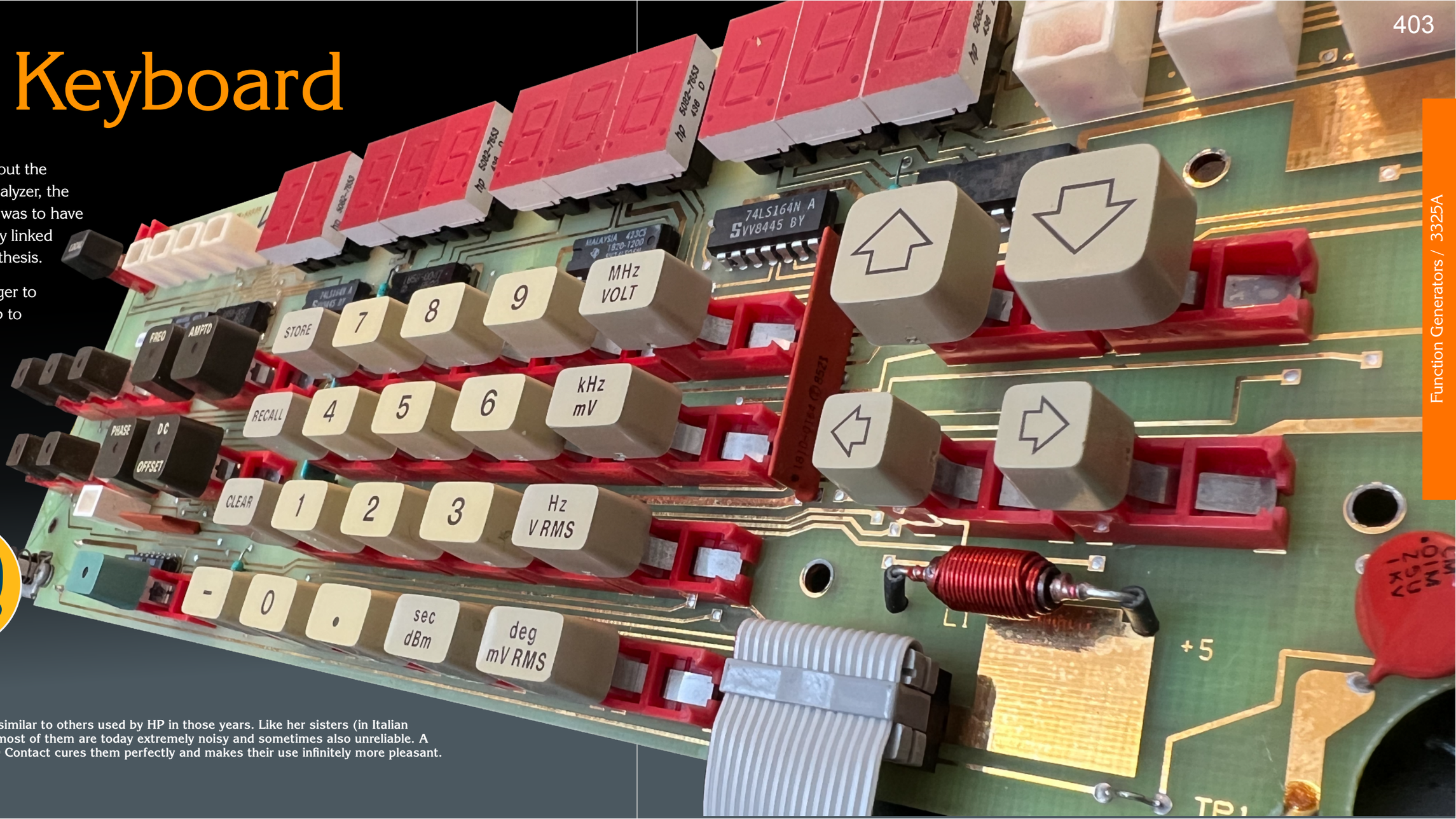


The Keyboard

As we say talking about the 8568B Spectrum Analyzer, the other big innovation was to have a **keyboard,** logically linked to the frequency synthesis.

You had not any longer to patiently tune a knob to obtain a desired frequency, but you could just “tell” the generator the frequency you wanted.

1978



The 3325A keyboard is similar to others used by HP in those years. Like her sisters (in Italian Tastiera is feminine...), most of them are today extremely noisy and sometimes also unreliable. A generous spray of WD40 Contact cures them perfectly and makes their use infinitely more pleasant.

Specifications

Specifications

As a **frequency synthesizer**, this instrument had a resolution of 11 digits and its sine-wave output covers an exceptionally wide range of frequencies, from 1 uHz to 21 MHz over 13 decades. Unlike other synthesizers, the phase of the output could be adjusted over a ±720° range with respect to an internal reference. Also, it could sweep the entire frequency range or any part of it with a phase-continuous sweep (no transients between frequency steps). In terms of synthesizer performance, it had low sine-wave distortion (-65 dBc) at audio frequencies.

As a **function generator**, the Model 3325A was noteworthy because of its frequency accuracy, waveform precision (triangles and ramps with linearities within ±0.05%), low-frequency capability (to 10^{-6} Hz), and programmability. Output amplitude was adjustable up to 10 volts into 500 ohm and the output could be offset up to ±4.5 Vdc. The offset could also be used by itself to provide a DC level up to ±5 V.

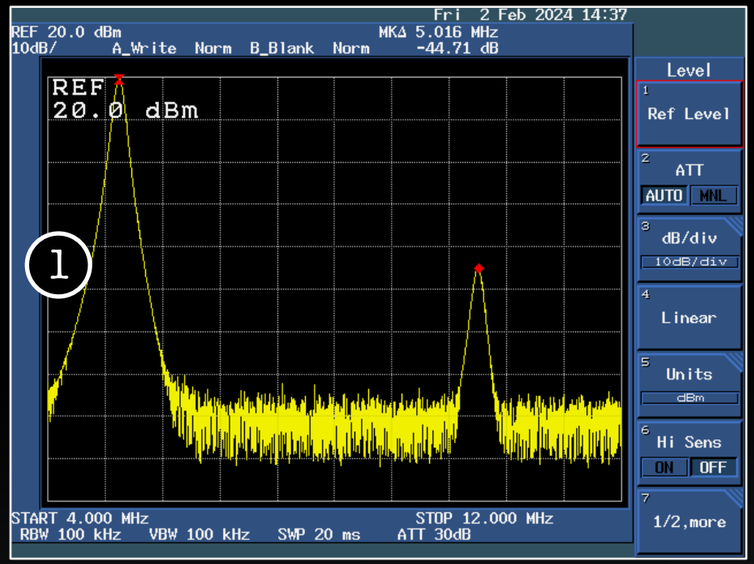
Provisions were also included for **phase modulating** any output function and for **amplitude modulating** the sine-wave output. An optional output amplifier (Option 002) increased the output amplitude and offset by a factor of four (into 500 ohm) up to 1 MHz.

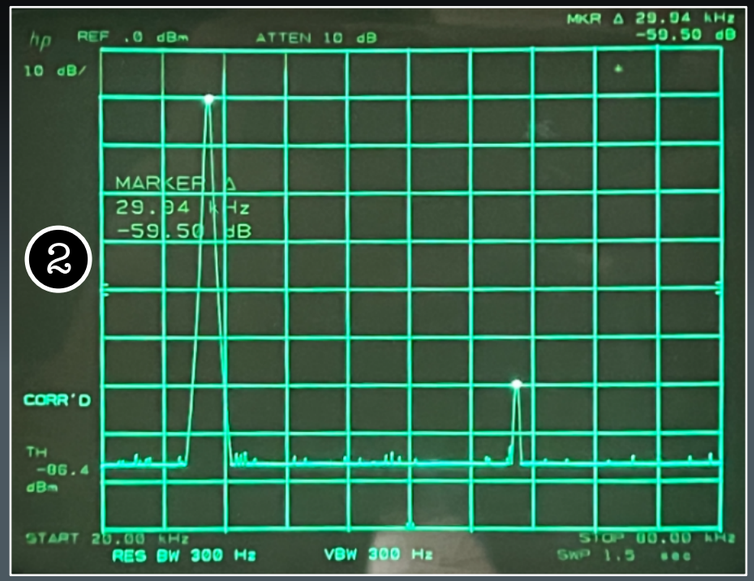
Several **convenience** features in the new instrument included front– and rear–panel sync outputs, a rear-panel 20-60 MHz high frequency output programmable from the front panel, and a 1-MHz reference output. The instrument could be phase-locked to any subharmonic of 10 MHz between 1 and 10 MHz and a high-stability oven-controlled reference oscillator was available as an option (001).

Another option (002) was provided for high voltage output (up to 40 V), but it imposed some limitations, so it was possible to disable it.

Harmonic distortion

I am not going to transcribe here the full 3325A specifications that you can find easily on the Internet. I believe it is more interesting to see how one of these specifications are today still met. I am talking about the harmonic distortion, which could be a critical point in a synthesized generator.





According to HP, signal purity, accuracy and stability were as good or better than earlier stand-alone HP synthesizers.

More precisely, they say that harmonically related signals are less than the following levels (relative to the fundamental) at full output for each range:

- 0.1 Hz to 50 kHz < -65 dB
- 50 kHz to 200 kHz < 60 dB
- 200 kHz to 2 MHz < 40 dB
- 2 MHz to 15 MHz < 30 dB
- 5 MHz to 20 MHz < 25 dB

In figure 1 you can see a measurement performed on the Advantest 31031 spectrum analyzer at 5 MHz: the second harmonic is at -45 dB below, a good result related to the specifications, but the 8640B is at -57, the analog wins, at least at not too high output levels.

Al lower frequency (figure 2) the 3325A still performs rather well (-60 dB instead of promised -65, picture taken on the 8568B).

Also the output levels seems to be still now very precise.

❶ Carrier at 5 MHz at 20 dB; second harmonic @ -45 dB

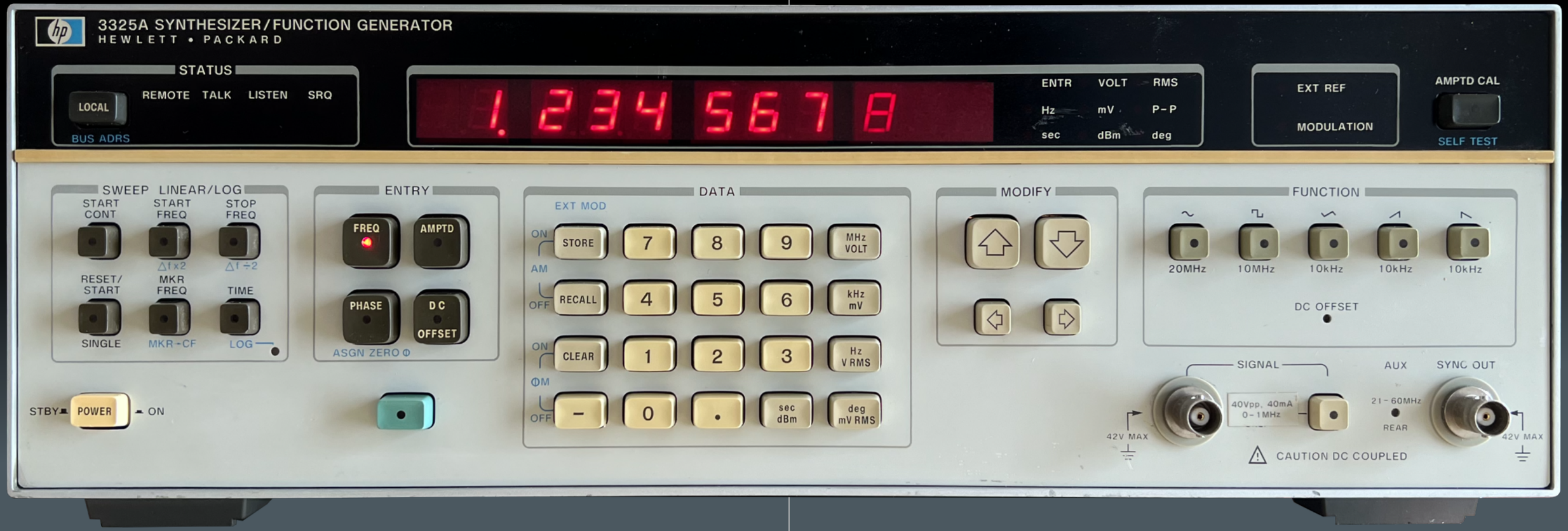
❷ Carrier at 30 kHz at 20 dB; second harmonic @ -60 dB

Front Panel

Even with just one seven-segment display, the front panel is still now very attractive. Well-designed and easy to use, is very intuitive, and allows to use immediately most of its functions, without reading the manual. Very nice the idea of a LED embossed in many keys. Limited the use of the shift: most of the functions have a dedicated button.

I find that its biggest limit, which was probably not too difficult to overcome, is the lack of period settings. You have so to use always Hz, kHz or MHz. Seconds are available only for the sweep time.

As already mentioned, all that, together with its stability and precision, make this instrument valuable still today, and remain rather expensive in eBay ads, up to $900. I purchased mine for much less, but it was faulty, and so I took some risk, whether I could not repair it. However I succeeded and am now very happy having it in my small laboratory, not just as a collector's item, but for every day work.



Architecture

Microprocessor based

In those years, HP was extensively introducing **microprocessors** to boost instruments' performance and functions. We saw before such introduction talking about the 3325A's almost coeval 8568A Spectrum Analyzer, for which a powerful uP was needed, and how they decided to use the only one that appeared capable of doing the job: the new processor under development in the desktop computer R&D labs at HP's Loveland, Colorado, facility. This microprocessor was intended to be used in the 9825A desktop computer, and is the same used in the 3325A, only known as "1820-1691", later said Nanoprocessor" (you can see it the photo on the left). This chip can also be found in a number of HP computer peripherals of the 98x5 desktop computer era, such as diskette drives or printer (I cannot check if it is really the same chip, because my 8568 is of the "B" type, in which they decided for an upgrade to a more modern Motorola 68000, much better performing).

All the functions within the 3325A are controlled by this microprocessor, enabling a broadened control capability, such as the ability to store and recall up to 10 sets of complete instrument settings (even if only while switched on), the ability to "tune" the output frequency by incrementing any display digit with up-down step keys as well as by entering a desired frequency with the numerical keypad, and extensive error checking that insures that the selected signal parameters are allowed for the functions chosen.

Also, the microprocessor control enabled the output amplitude to be selected directly in the desired units (Vpp, Vrms, or dBm / 50 ohm).

Extensive **self-test capabilities** are also included. The instrument is also fully **programmable** through the HP Interface Bus (HP-IB/GP-IB). It is thus readily incorporated into HP-IB-linked automatic test systems.

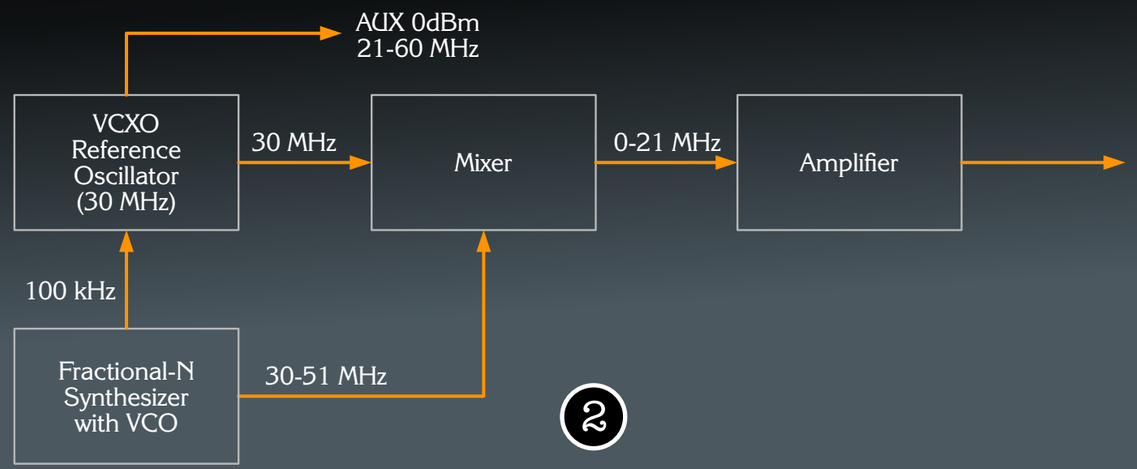
In the photo, the 1820-1691 microprocessor. Its production process was not yet uniform and each chip required a different bias voltage. When the chip has to be replaced, also a voltage divider on the board must be adapted.

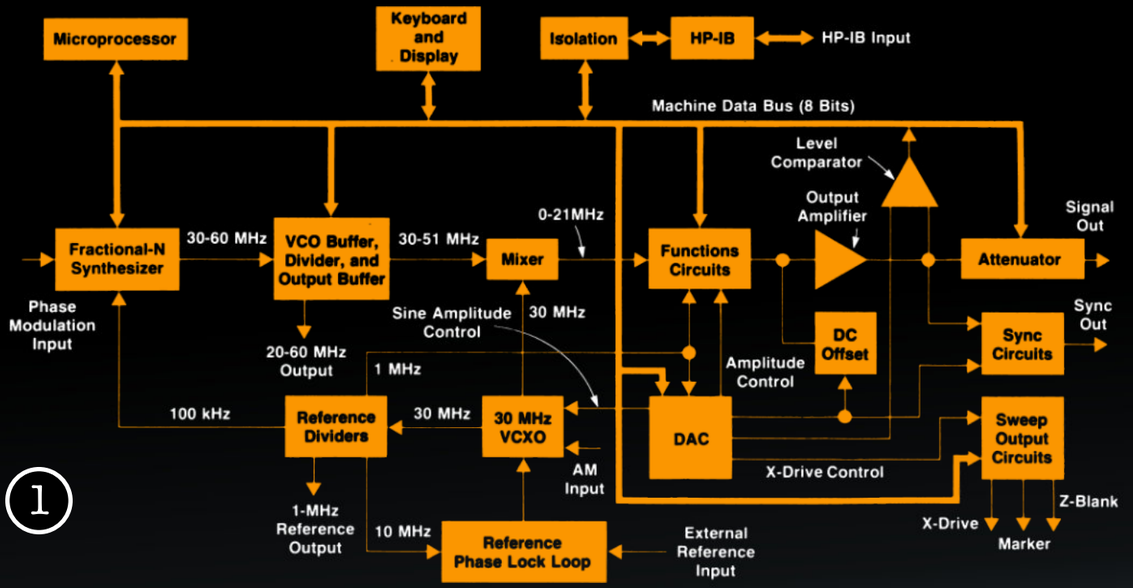
Block diagram

All 3325A operations are controlled by the microprocessor, which enhances the versatility and "friendliness" of the instrument. Operating conditions are entered by way of the front-panel keyboard or through the HP-IB interface.

Figure ❶ on the right reports the 3325A's block diagram, but its probably better to start from the simplified one below (❷), which describes the frequency generation, i.e., the "production". All the rest can be classified as "services".

The frequency generation is implemented by mixing two signal: one from a **30 MHz Reference Oscillator**, the other from a **Fractional-N Frequency Synthesizer**, which generates an output frequency in the range 30-51 MHz, and which we are going to describe later in detail. The Synthesizer uses a 100 kHz signal, obtained dividing the 30 MHz Reference. If you require a 10 MHz signal, the VCO produces a 40 MHz frequency, and the difference (40-30) gives the output signal. This approach makes easy to produce **swept output**: the microprocessor simply programs in sequence the needed frequency values (even if rather slowly).





The **Mixer output** is **amplified** and then used directly as the sine-wave output, or to generate the square, triangle, or ramp functions.

The output level is set by a programmable 10 dB/step **Attenuator** and **Amplifier** with programmable gain. A **Peak Comparator** at the output of the final amplifier is used during an automatic routine to calibrate the output amplitude.

All the analog levels within the instrument are controlled by a **D-to-A Converter** with multiplexed output, which allows to set six different parameters: signal amplitude, DC offset, DC offset error, level comparator reference, X-Drive and auto-zero. We will return later also on this point.

❶ 3325A block diagram.
❷ Frequency generation block diagram.

My 3325A



My unit comes from **Radiosurplus Elettronica**, probably the best surplus supplier in Italy. Their prices are not always the cheapest, but their quality is. I bought this unit, declared as non-working, but in excellent conditions. We will talk extensively about its repair.

Note: the seven-segment display is multiplexed and the refresh rate is rather low. For this reason, it was not easy to take photos of it. In this case, the number was 1.234567896, but the first four digits "escaped" to my iPhone...

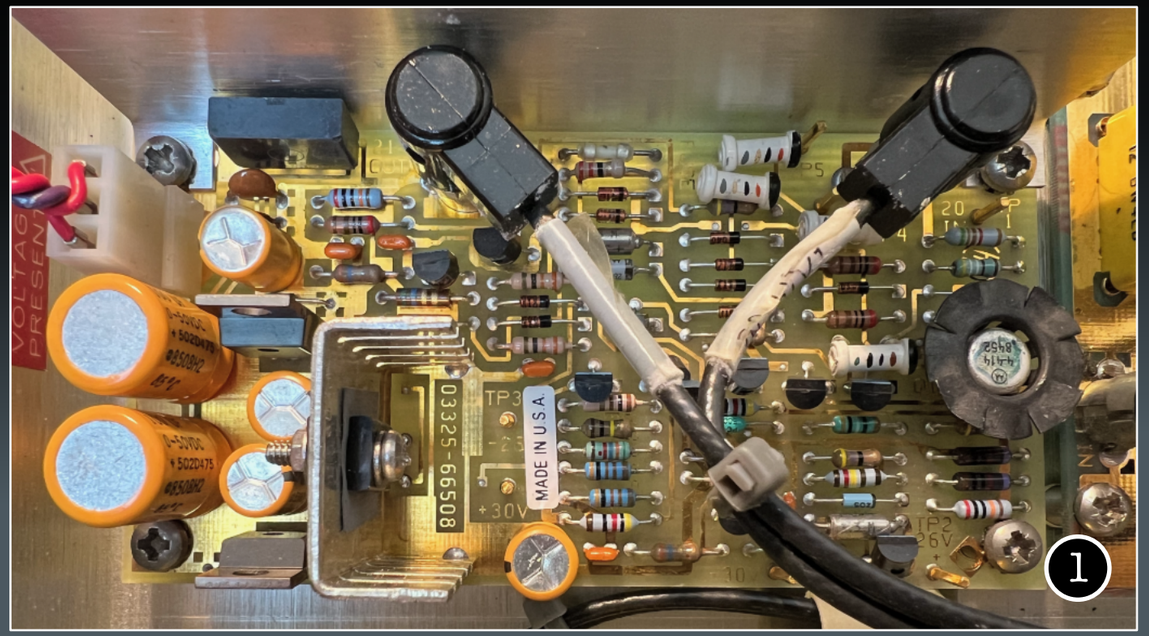
Options

Two possible options were provided to 3325A's purchasers.

Option 001 Oven High Stability

Option 001 is a temperature stabilized 10 MHz oscillator which provides improved frequency stability. The output from this oscillator is at the rear panel 10 MHz OVEN OUTPUT connector. This output must be connected to the EXT REF input.

- Standard stability: ±5 x 10-6 per year (20° to 30°C), i.e., 5 Hz per MHz.
- Option 001 stability: ±5 x 10-8 per year (0° to 55°C), i.e., 0.05 Hz per MHz. Aging Rate: ±5 x 10-8 per week (after 72 hours continuous operation); ±1 x 10-7 per month (after 15 days continuous operation).



Option 002 High Voltage Output

Frequency Range

- Sine and Square Wave: 1 μHz to 1 MHz;
- Triangle and Ramps: 1 μHz to 10 kHz

Amplitude

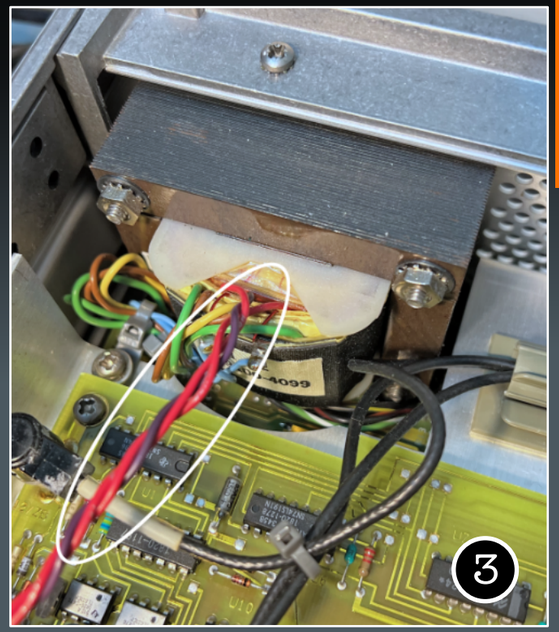
- Range: 4 mVp-p to 40 Vp-p (≥ 500Ω, < 500F load) maximum output current, ±40mA
- Accuracy (at 2 kHz): ±2% of full output for each range
- Flatness: ≤ 10% of programmed amplitude

DC Offset

- Range: 4 times the range of the standard instrument
- Accuracy: ±(1% + 25 mV) of full output for each range

❶ A8 Board, Option 002.
❷ A9 Board, Option 001; the This photo comes from https://bukosek.si/hardware/collection/hp-3325a.html
❸ The transformer has dedicated wires for the Option 002. Probably, they are always present even without the option, to allow however to install it at a later time.



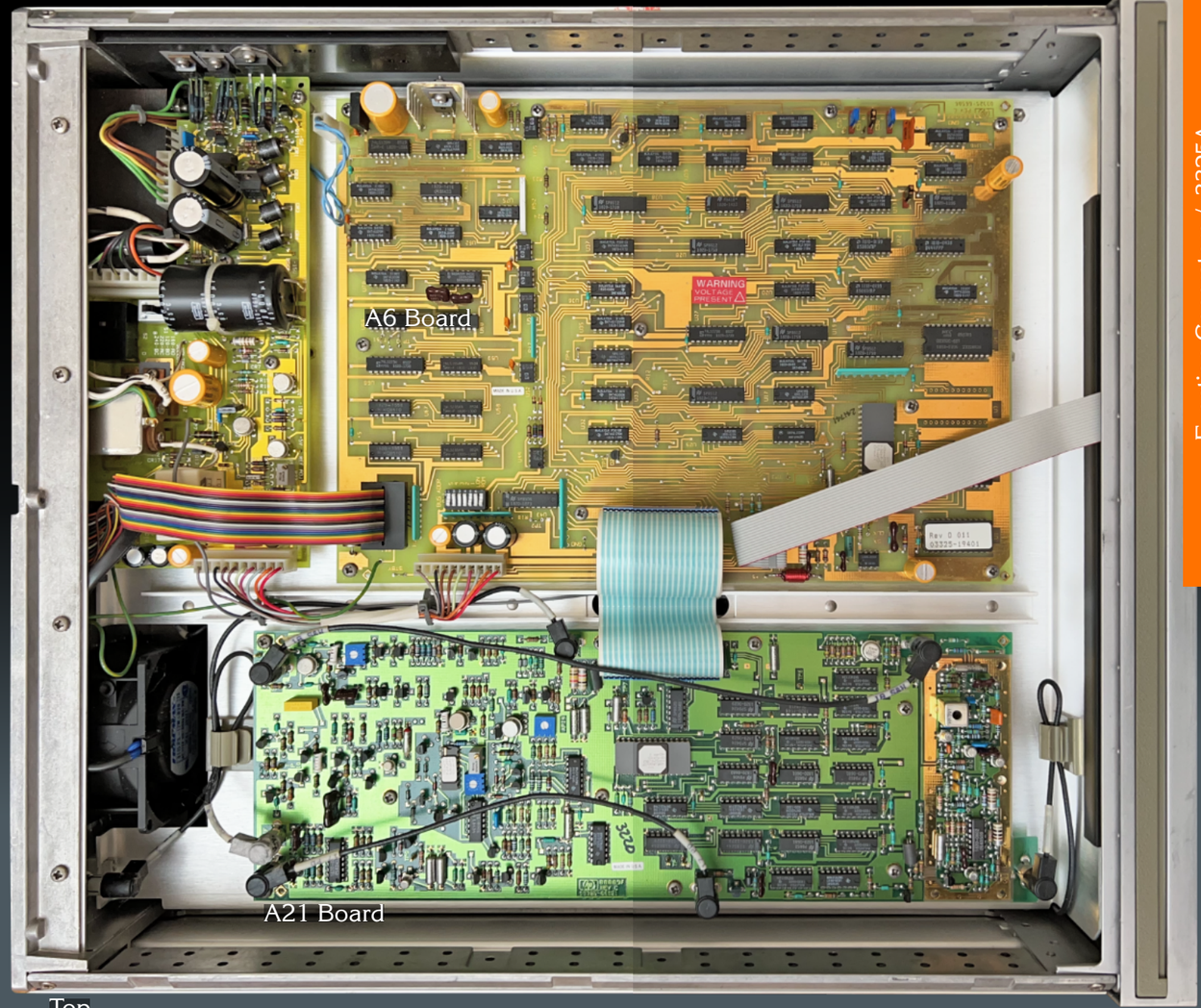


Top & Bottom

Incredibly clean and easy to access, the 3325A is one of the most serviceable instruments I dealt with. In these photos, the metal shields have been removed to show all the components.



Bottom



Top

Understanding Connectors



Surely there is a logic in the output signal connectors, but I could not decode it, and some explanation is due.

- **SIGNAL connector**: this is the main connector and is used for 50-ohm sine, square, triangle and ramp waves. Sine waves can range from 0.000001 Hz to 20 999 999.999 Hz. In the standard model (i.e., without Option 002), you can choose to send this signal to the rear panel SIGNAL connector by pressing the REAR ONLY key. The lighted indicator in the center of this key denotes that the signal output is at the rear panel. A lighted "Signal, Rear Only" annunciator indicates that the rear panel signal output is active, and only one connector (front or rear) can be active at the same time.
- **AUX 21-60 MHz 0dBm**: this connector, on the rear panel, is something like an “extra bonus” that you get for free, and can produce a signal at frequencies between 19000000.001 Hz and

60999999.999 Hz at a nominal level of 0 dBm into 50 ohms. It is more a square wave than a sine and cannot be controlled in amplitude. The output is automatically switched to this rear connector when frequencies of 21 000 000.000 Hz or higher are programmed. To use frequencies from 19 to 21 MHz, first select 21 MHz, then use the up/down key to descend below 21 MHz. When in this frequency range, no signal is emitted to the front and a "21-60 MHz Rear" annunciator is lighted.

Things changes if you have the Option 002 installed. In this case:

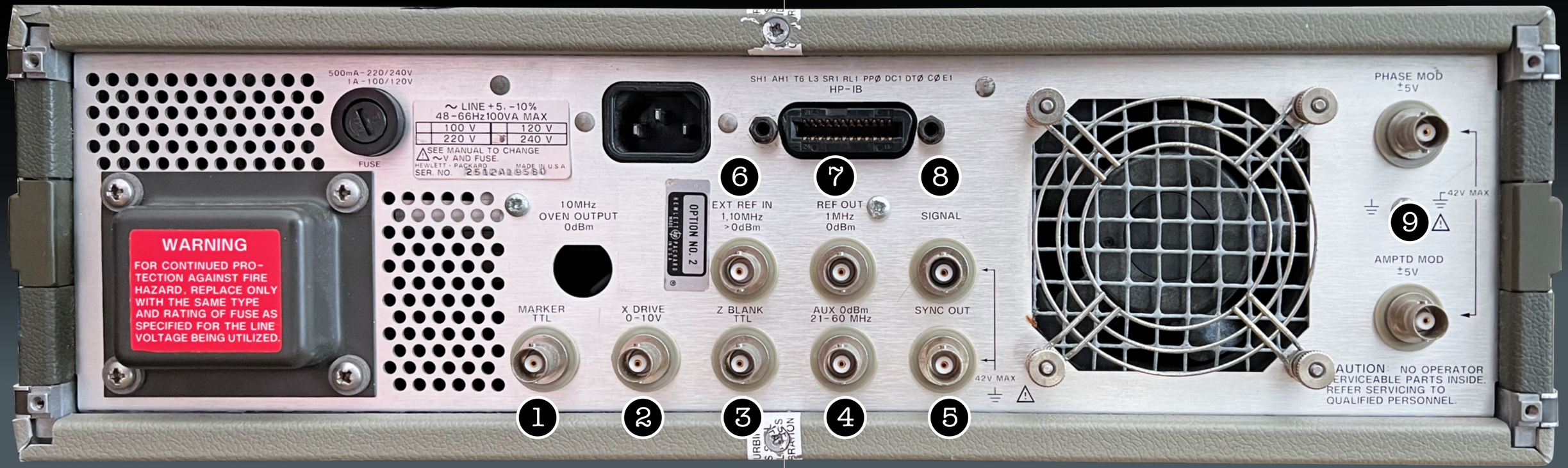
- the rear SIGNAL connector is present but inactive;
- if you don't press the SIGNAL button (key indicator off), the front SIGNAL connector behaves like the standard model;
- if you press the SIGNAL button (key indicator on), the front SIGNAL connector can provide a maximum output of 40 V p-p into a 500-ohm load. Maximum frequency for sine and square wave functions is reduced to 1 MHz, while for triangle and ramps remains 10 kHz.
- for triangle and ramps). The rear panel signal output is inactive (no internal signal connection) if the instrument has this option installed.

Instructions are given in the Operating and Service Manual, Section VIII, Service Group M, for activating the rear panel signal output in one of two ways:

- placing the standard/high voltage output on the rear panel only, disconnecting the front panel signal output;
- disabling the high voltage output and enabling the standard front/rear output configuration.

Resuming: the 3325A can give its performance in the range 0-21 MHz, but can however supply a 19-61 MHz signal where it can be useful, and the Option 002 allows to increase output voltage to 40 V.

❶ MARKER TTL - high to low TTL compatible voltage transition at selected marker frequency, sweep up only
❷ X-DRIVE 0-10V - 0 to +10 V DC linear ramp proportional to sweep frequency (sweep up only) s
❸ Z BLANK TTL - low at start of sweep, high at stop. Remains high until start of next sweep
❹ AUX 0dBm 21-60 MHz - see text
❺ SYNC OUT - same as SYNC on the front panel. It outputs a front at the signal zero crossings
❻ EXT REF IN 1,10 MHz >0 dBm - external Reference signal, automatic detection
❼ REF OUT 1 MHz 0 dBm - reference signal output
❽ SIGNAL - see text
❾ PHASE (upper) and AMPLITUDE MOD ±5V (lower) modulation inputs

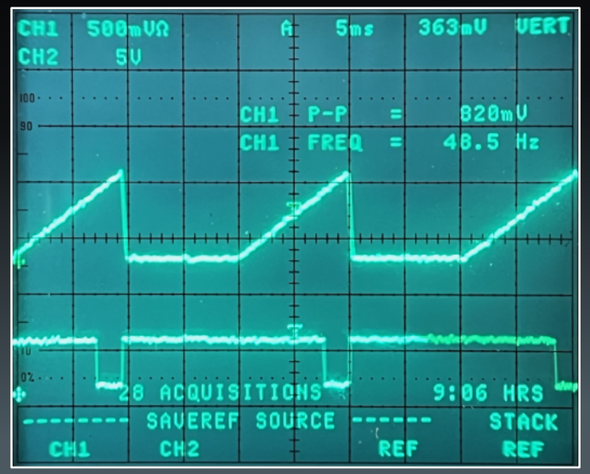


Some Waveforms

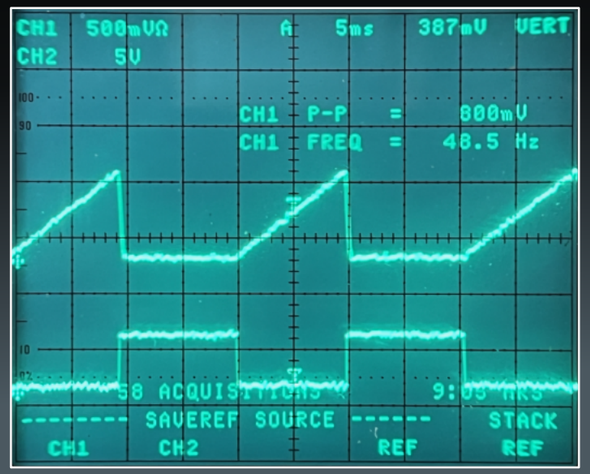
Here are some waveforms from the 3325A's connectors. The small circled numbers are related to the circled numbers in the photo on the previous page.



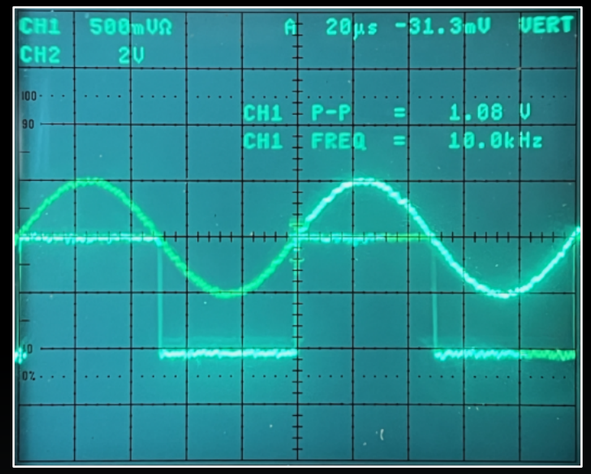
When probing with the oscilloscope or taking measurements with the VOM, never forget that there is a separate ground on some internal frames.



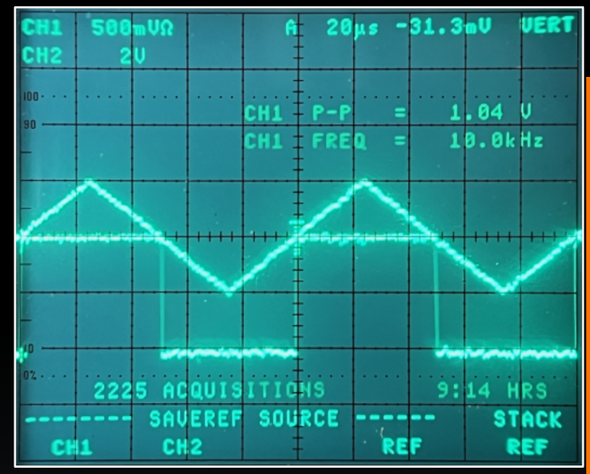
❶ MARKER TTL output (below), related to the X-DRIVE signal (above). MARKER TTL goes low when the swept frequency crosses the value set from the front panel.



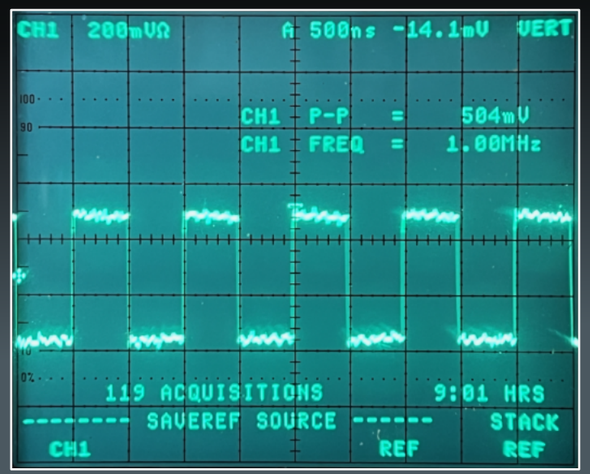
❷ X-DRIVE 0-10V - 0 to +10 V DC linear ramp proportional to sweep frequency (sweep up only)
❸ Z BLANK TTL - low at start of sweep, high at stop. Remains high until start of next sweep



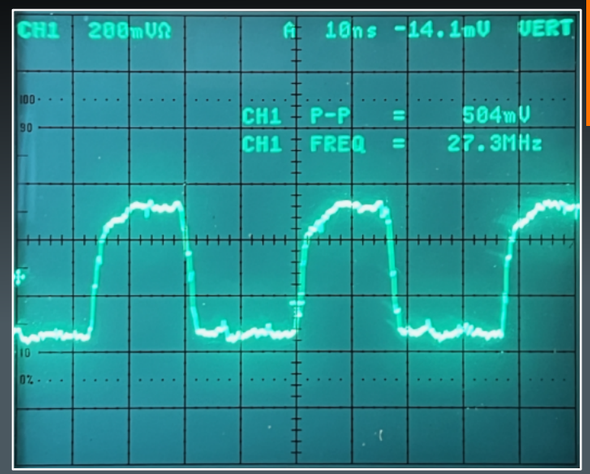
❽ SIGNAL OUT related to ❺ SYNC - note that with the Option 002, the SIGNAL OUT is produced only on the front panel. SYNC is produced on the zero crossing.



The same as that on the left, but related to a triangle instead of a sine.



❼ REF OUT 1 MHz - derived from the 30 MHz reference, has a frequency of 1 MHz



❹ AUX 0 dBM 21-61 MHz output - as described in the text, this signal is to be considered outside the "official" range of the function generator and is more a square wave than a sine.

Foreword to Fractional-N PLLs

Reading this book, you could note that I often use text from other documents, even if rearranging them. Anyway, I try to never make a “bovine copy” of these documents and, above all, I try to always follow these guidelines:

- to talk only about the equipment I own, and which really I studied/repaired/restored;
- to write only what I could fully understand, trying hard to make it more understandable to others.

In the case of the 3325A, I knew that I bought a faulty equipment, and so I tried to prepare myself for a complex battle, should the fault be in the most complex part of it, i.e., the Fractional-N Frequency Synthesizer. So, I used the time I had to wait for receiving the shipment to study this part of the circuit, finding it very interesting and finding myself more and more involved in it.

If you want formulas, you can satiate yourself with lot of documents from Internet but I was not able to find a clear and simple explanation of the basic operation of the Fractional-N PLL.

I started with a description where most of the text was taken from the 3325A manual or from HP Journal 1/1979, where the the 3325A is described, but it didn’t convinced me first, so I tried to revise it until most of the basic concepts have been rewritten from scratch.

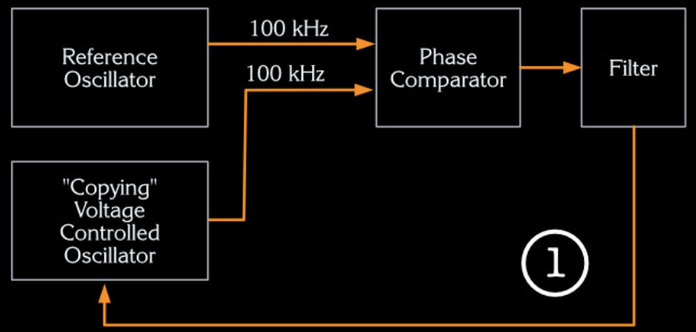
I had to work for several days to put together what follow, because the matter is complicated and my limited knowledge didn’t help… I will be grateful to those who would send me their suggestions or corrections to make clearer the description of this very interesting circuit.

In the photo on the left: A21 board, with the 28-pin 1820-2204 U19 IC (about in the middle), the the fractional-N control chip.

Integer-N Phase Locked Loop

Suppose you have a **Reference Oscillator** (ROSC, normally very stable), for example at 100 kHz, and that you want to "copy" its signal by mean of a second oscillator, which by itself runs at approximately 100 kHz, whose exact frequency is controlled by a voltage (**Voltage Controlled Oscillator**, VCO). You can use the circuit shown here, said **Phase-Locked Loop**. When the VCO frequency drifts, the **Phase Detector** (PHD) generates pulses as shown in Figure 2 (non-locked above and locked below). These pulses are then filtered to produce a DC voltage proportional to the phase difference between the two waves used to drive the VCO to correct its frequency.

Thus, the VCO remains "locked" to the ROSC even when it would like to drift. This well defined "locked status" can easily be detected and a LED (or other) can be lit to signal this condition.



Integer-N PLL

The circuit we just saw is not very useful, because it provides us with a waveform we already had from the ROSC. But imagine we add a by 2 divider on the VCO output, In this case, the VCO will operate at 200 kHz instead of 100. By using a **programmable divider**, we will be able so to produce many different frequencies, with the same stability of the ROSC, even if produced by an unstable VCO.

In the 3325A, the ÷N number can be only a 3-digit integer between 300 and 500; consequently, the VCO frequency range is normally from 30 MHz to 50 MHz; for example, if we set ÷N to 400, like in figure 1, the VCO frequency will be 40 MHz; with 401, the VCO will produce 40.100 M Hz; with 402 40.200 MHz and so on. Just changing the number ÷N, we can modify the output frequency value.

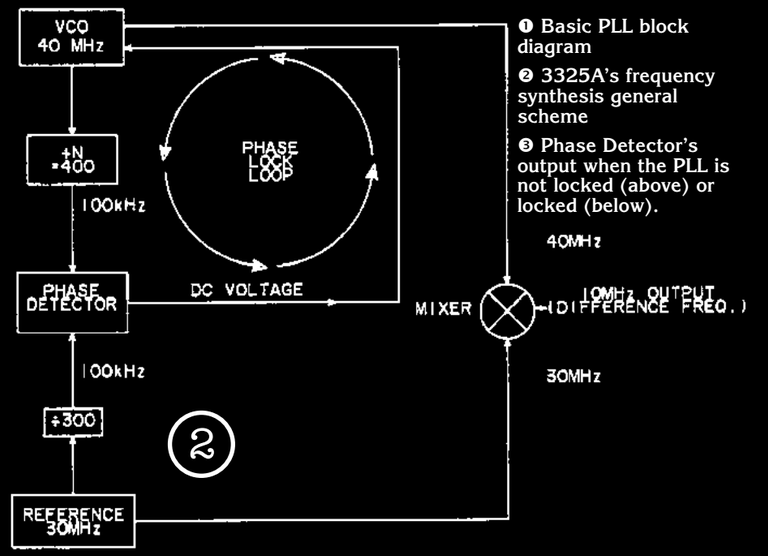
The above described operation allows only to change the ÷N number and is called **Integer-N PLL.**

3325A output signal

In the 3325A, the VCO signal is not used directly to produce the generator's output, but is mixed with the 30 MHz from the Reference Oscillator. In consequence, the frequency produced by the PLL in the previous figure 1 is 10MHz (40 - 30 MHz = 10 MHz). For example, if ÷N is 398, the VCO frequency is adjusted to 39.8 MHz (398 × 100 kHz) and the output is 9.8 MHz.

The ÷N number is determined by control circuits in response to front panel or remote programming; it takes the 3325A about 50 milliseconds to make a change.

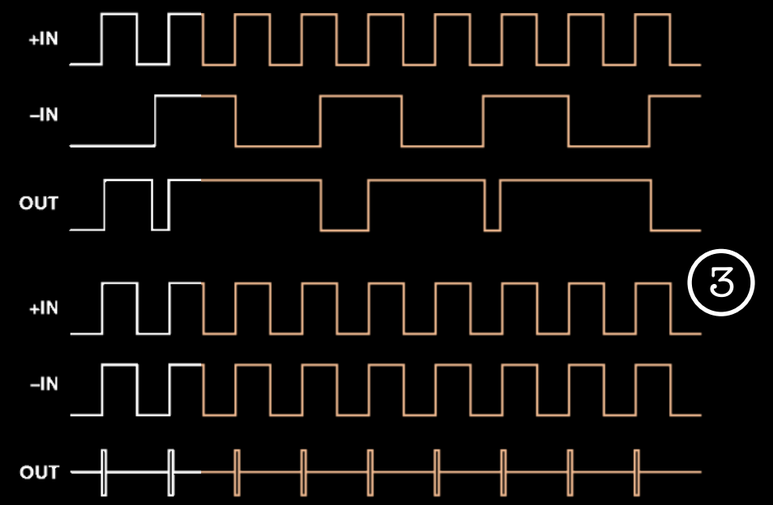
Practical Note: the 3325A VCO control voltage comes from the connector A21J18A (cable marked 81 S-H). A +10 V input produces 30 MHz frequency; +5V=42.6 MHz; -3 V=60.9 MHz.



❶ Basic PLL block diagram

❷ 3325A's frequency synthesis general scheme

❸ Phase Detector's output when the PLL is not locked (above) or locked (below).



Fractional-N Phase Locked Loop

Fractional frequencies

Let's now discuss the most interesting part of the 3325A that makes it so special: the **Fractional-N PLL** and its relevant benefits.

Up to this point, we have considered only the situation of the Integer-N PLL, where ÷N is a whole number consisting of three digits.

The question is: how to generate a **fractional frequency**, like 10.04 MHz? Acting on the ÷N number we can only generate 10 MHz (with VCO = 40 MHz) with ÷N=400 and 10.10 with 401.

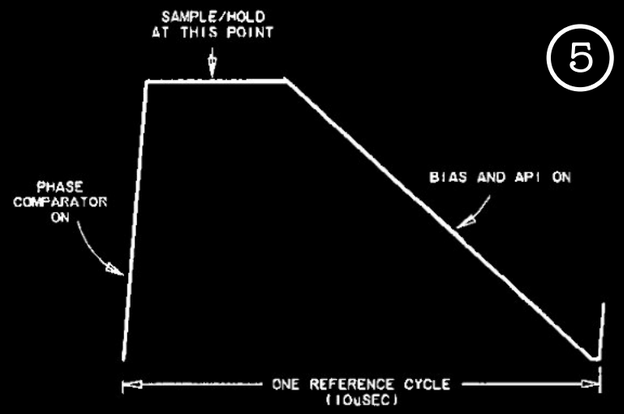
To set the VCO at 40.04 MHz, the ÷ N number should be 400.4. This number is referred to as **÷N.F**. The number 400 is represented by N, and the fraction 4 may be called **F**, or the **fractional N**).

A PLL circuit capable of managing the ÷N.F number (i.e., a number with an integer part N and a fractional part F) is called **Fractional-N PLL**.

More about the Phase Detector

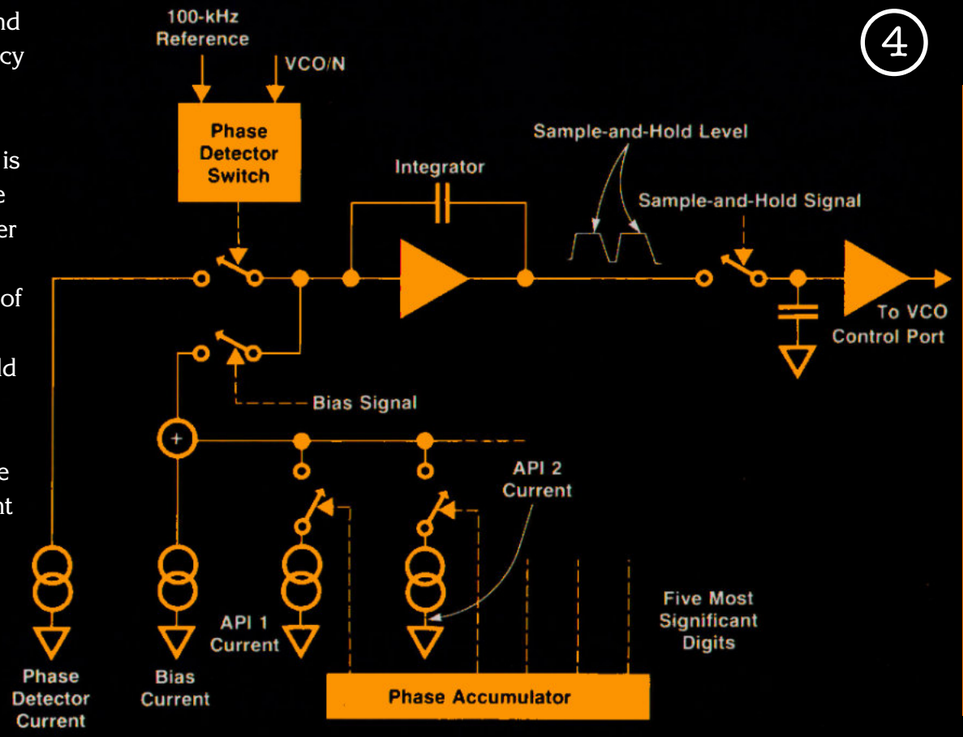
To proceed, we need some further discussion about the **Phase Detector Block** (figure ❹).

Every ÷N VCO pulses, a pulse from the PHD is sent to an **Integrator**. The control voltage to the VCO is the output of a **Sample/ Hold Amplifier** which samples the Integrator output at the proper time and at regular intervals. Ideally, this voltage would be exactly the same at each



5

sampling time and the VCO frequency would remain constant. Let us assume that this is true, and that the ÷N Since number is 400. In this case, the output of the phase comparator would be a series of pulses of equal width. Each pulse turns on a current source which causes a given amount of charge to be placed on the integrator.



4

At a specified time, this voltage is stored on the Sample/Hold amplifier capacitor (figure ❹). The integrator output is illustrated here on the right (figure ❺). The charge slope is much greater than the discharge slope because the phase comparator current source has about ten times the magnitude of the bias current source.

Immediately after a sample, the bias current source is turned on to discharge the integrator capacitor to the level it held before the phase comparator current was allowed to charge it. If this were not done, the charge would continue to accumulate to the limit permitted by the power supplies and remain at that level (nullifying the entire PLL scheme). The bias current is controlled by a pulse from the fractional ÷N control IC, which we will see next.

❺ Integrator and Sample & Hold block diagram
❹ Integrator's output

Fractional-N PLL

As mentioned, I had some difficulties understanding it (and probably I didn't understand it fully right now), but things got easier for me, after I understood two basic concepts that are not so evident in the documentation I could find:

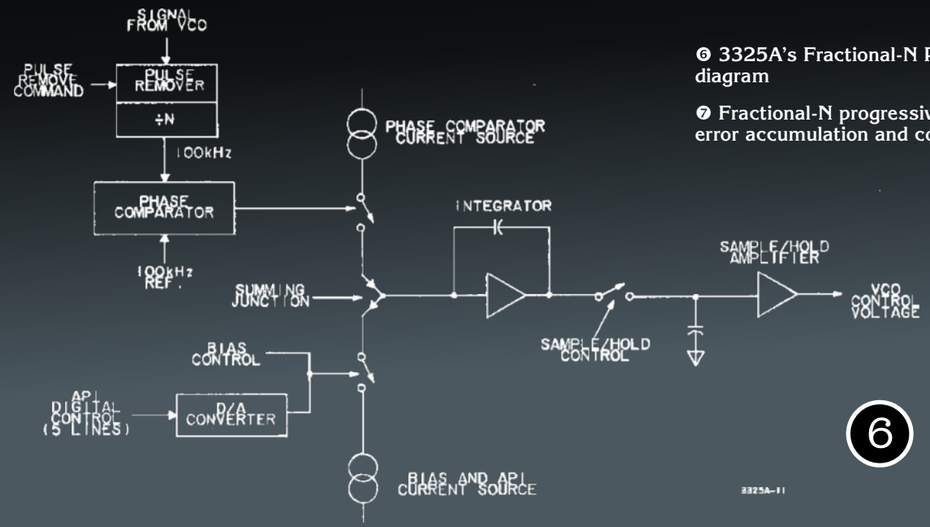
- **Principle 1**: this PLL **toggles** the divide ratio between N and N+1 periodically to create an average value equal to N.F;
- **Principle 2**: the fractional part works in **open-loop**, i.e. the actions are in some way "unilaterally programmed" by the controller to achieve the desired results.

Principle 1 tells us that if my target frequency were 10.05 MHz, I can obtain it alternating a ÷400 cycle with a ÷401 cycle, i.e., **removing** one cycle from the divider count once yes and once no. We will see how to obtain the intermediate values.

To build-up the Fractional-N PLL, two additional circuits are required (figure ❻):

- a **Pulse Remover** block.
- a **Digital-to-Analog Converter** (D/A);

To explain all that, I found easier to reverse the standard approach, and start with the cycle removing description.

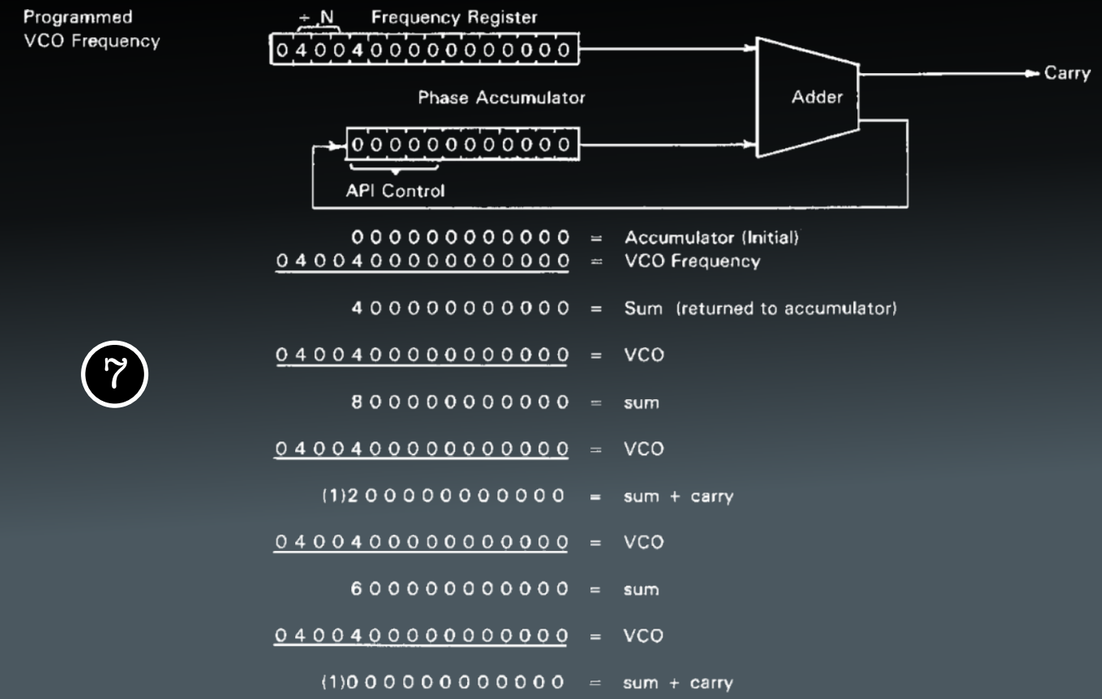


❻ 3325A's Fractional-N PLL block diagram

❼ Fractional-N progressive phase error accumulation and correction.

Removing a cycle

We saw that the using Principle 1 we can rather easily produce a 10.05 frequency. The problem is now how to generate the 10.04 MHz of the above example? That could be translated in another question: "how to decide if and when is a cycle removal required?". For doing that we follow the Principle 2, i.e., we operate in an open-loop way, keeping a separate account of the desired phase shift in a special register, named **Phase Accumulator**. It is 12-digit long and starts from "000000000000". At every sample cycle (every 10 us in the 3325A), we add to it a constant value which specify the desired phase shift (figure ❼). At a certain point, the counter will obviously overflow: that's the moment to add a cycle (i.e., to remove one from the count, making an extra cycle to be added, for example dividing by 401 instead of the "normal" 400). Rather simple, isn't it?



Each carry initiates a pulse remove command.

The constant value to be added

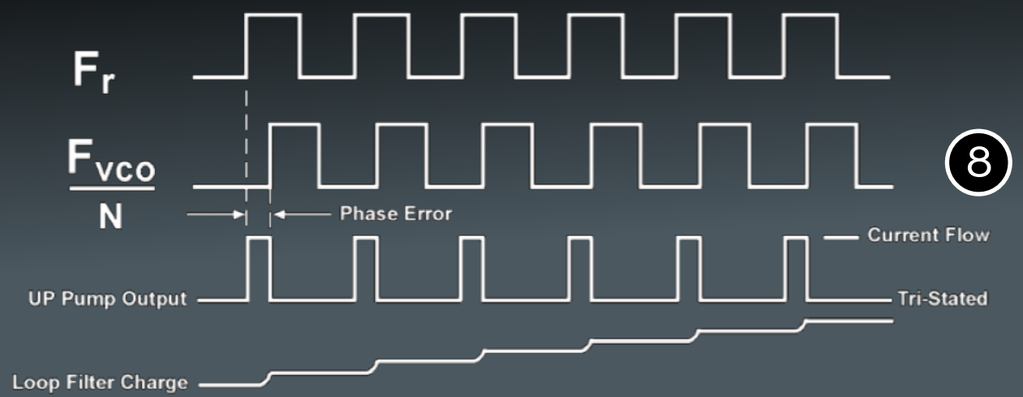
But which is the constant that we must add? The frequency required by the user is contained in a 15-digit register (12 of them displayed on the front panel). The first 4 digits are the integral part (e.g. 400), the others are the fractional one (e.g., 400000000000). The value to be added is exactly the fractional part, as shown in the figure ❻ on the previous page. Each time the Accumulator overflows, a pulse remove command is issued (i.e., a cycle is added). As another example, if the output frequency were 10.09 MHz, the fractional N would be .9, and a pulse remove command would be required for 9 out of every 10 reference cycles.

It's enough?

If this description convinced you that toggling an extra cycle we can obtain the desired frequency, we need also to convince the Phase Discriminator (PHD) to not get mad with our manipulations. Let's start reminding how the phase detector works.

Phase Detection

Figure ❽ explains PHD's operation. At each cycle, a phase error is detected and the phase error pulse increases the charge on the Sample/Hold. In this diagram, we can suppose that the VCO is not working (or still not intervening), because normally it should have changed the frequency value and zeroed the phase error pulse, but the diagram is however interesting to have a visual image of the PHD operation.



Tricking the VCO

The basic count-by-N.F scheme just described requires certain refinements to become a viable technique.

If the VCO operated at 40.04 MHz and ÷N were 400, then the divided VCO signal to the phase comparator would be 100.1 kHz and would be compared to the 100.0 kHz reference. This would result in an increasing phase comparator charge current to the Integrator, to force the VCO frequency to reduce to 100 kHz (remember that VCO decreases its frequency with a higher input voltage).

In other words, when the desired output frequency is not an integral multiple of the reference frequency, the VCO/N pulse gains a fractional part of a cycle with respect to the reference each time it occurs. Thus, the phase detector pulse becomes wider and the integrator ramps up further during each succeeding reference cycle, as shown in ❻.

But working in fractional mode, this is not what we want: we wish that, with the pulse removal, the VCO stays at 40.04, so we need to avoid that the phase error might attempt to correct it.

To do that, we need to ramp down the integrator further each time so the integrator ramp up will always end at the same level, and the desired fractional frequency is kept.

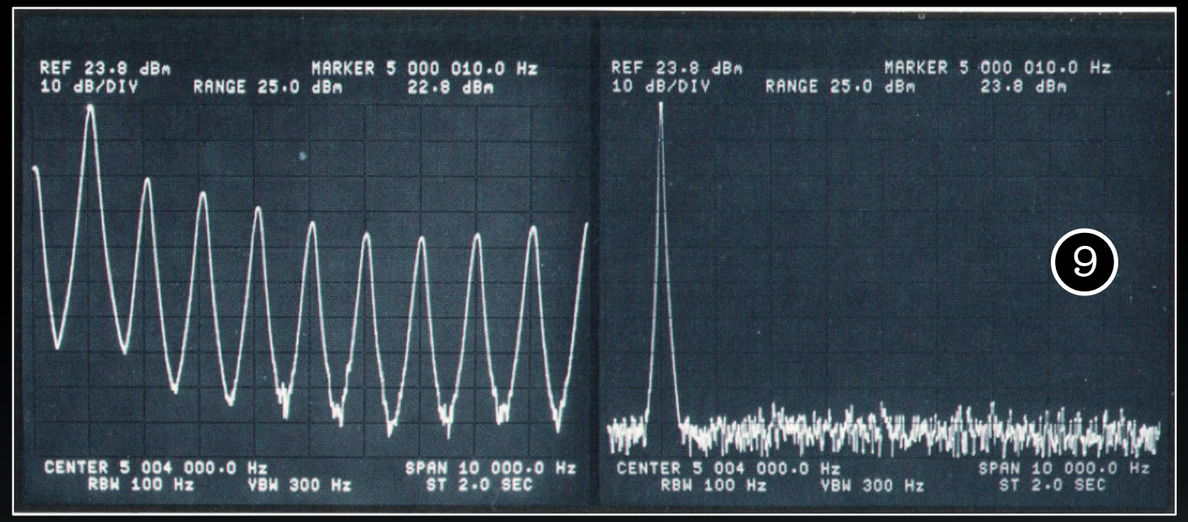
Canceling the increased charge

We said that to keep the desired intermediate frequency, we need to cancel the increased charge coming from the PHD. This is done subtracting current from the bias current, so that the VCO remains at 40.04 MHz on the next cycle. Once more, Principle 2 helps us. The controller "knows" how much the bias current must be reduced for each accumulator value, and does that by mean of the D/A converter: its current is subtracted from the bias current to discharge the integrator to the proper level during each sampling period, effectively cancelling the increased charge from the phase comparator.

What we have described goes by the name of **Analog Phase Interpolation** (API), which prevents the resulting large transient in the phase-error signal from disturbing the VCO loop. Without it, for example, cycle removals would cause the phase detector to detect a 360° phase error every time a pulse is deleted. Practically, it anticipates a pulse deletion and makes corrections to the integrator

❽ Increasing charge in the PLL filter

output, so large error signals are not transmitted to the VCO, with important benefits also on the spurious emissions. Picture ❾, taken from HP Journal 1/79, shows the effects of analog phase interpolation on the frequency spectrum. Spurious output frequencies are evident in the photo at left, which shows the spectrum of a 5.001-MHz sine-wave output without the use of API. Photo at right shows the spectrum of the same output with API.



Implementation

The ÷N (Fractional N) counter consists basically of three presettable counters in series. The counters for the two most significant digits (of the 3-digit ÷N number) are decade counters. The least significant digit counter consists of a ÷5 counter and a ÷2 prescaler, which can be made to divide by three as necessary. Presettable counters are used because ÷N must be variable, as explained below.

The preset number that is loaded into the counter in BCD (binary coded decimal) form is the 9's complement of the N number. N is determined by the first three digits of the VCO frequency.

To determine the 9's complement, ÷N is subtracted from 999 in the fractional N control IC.

❾ Effects of analog phase interpolation (API) on the frequency spectrum of the produced signal (from HP Journal 1/1979). On the left with no API, on the right with API. The effect is striking.

The ÷N counter begins at the preset number (599 in example 1), counts to 999 and then reloads the same number unless a new frequency has been programmed.

One output pulse occurs for each time the counters reach 999; consequently, if 400 VCO cycles (599 to 999) are counted for every output pulse, VCO has been divided by 400. The output pulse is derived from the bias pulse issued by the **Fractional N Control IC**. To provide the proper stable phase relationship to the VCO signal, this pulse is clocked first by VCO÷10, then VCO÷2, and finally by VCO.

In example 2, ÷N is 301, so the counter must count 301 VCO cycles during each reference period. Normally only an even number of cycles could be counted because the least significant digit ÷5 counter is counting VCO÷2 from the prescaler. Therefore, in order to count an odd number, the prescaler is forced to count one additional pulse during each reference period. To accomplish this, the pulse remove circuits are enabled when the least significant (BCD) bit of the least significant digit of the preset number is even, as is the case in example 2 (decimal 8 = binary 1000). Then the negative-

	Example 1	Example 2
Sine wave output	10 000 000.0 Hz	100 000.0 Hz
Reference frequency	20 000 000.0 Hz	30 000 000.0 Hz
VCO frequency	40 000 000.0 Hz	30 100 000.0 Hz
÷N	40 0	30 1

going pulse from the preload one-shot changes the prescaler to ÷3 for one cycle. The pulse remove

	999	999
÷N	400	301
9's complement	599	698

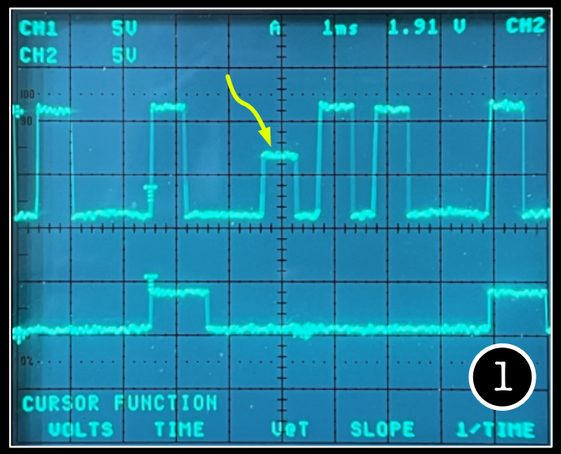
action associated with fractional N is independent of and in addition to the odd number count.

The chip clock counter output is the prescaler output divided by five. The Q output from this counter goes to the fractional N control IC and is used to clock data in and out of the four shift registers within the IC. The counter Q output is used in the ÷N.F counter output synchronization and to clock the cycle start flip-flop.

The cycle start flip-flop is set by the Q output from the preload flip-flop and is cleared by the next trailing edge of the chip clock signal. A cycle start pulse occurs at the time the ÷N least significant digit is preloaded, which is once every reference period. Cycle start is used to initiate operations within the fractional N control IC. It is also used to set the pulse remove circuit when ÷ N is an odd number.

e-Verniers

We were used that every instruments had one or more verniers to set parameters, such, for example, the output amplitude. Among the firsts, the 3325A introduced something that, with a modern term, we could today name “e-Verniers”, i.e., not a physical control but the capability of the processor to adjust it by mean of software.



DAC control

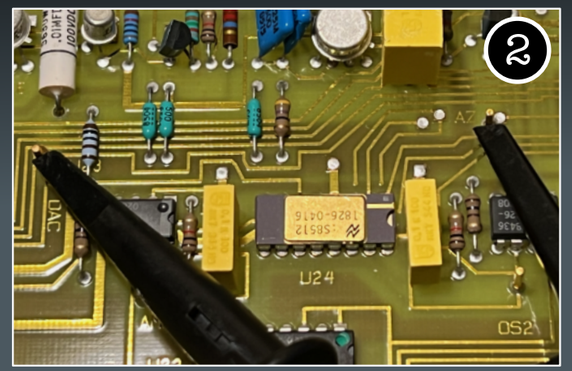
This is performed thru a 4½ digit Digital-to-Analog (D/A) Converter that supplies the analog voltages, which controls signal amplitude, DC offset, level comparator reference voltage, sweep X-Drive output, and corrects for DC offset error. In addition, it supplies an auto zero voltage to its own current sources.

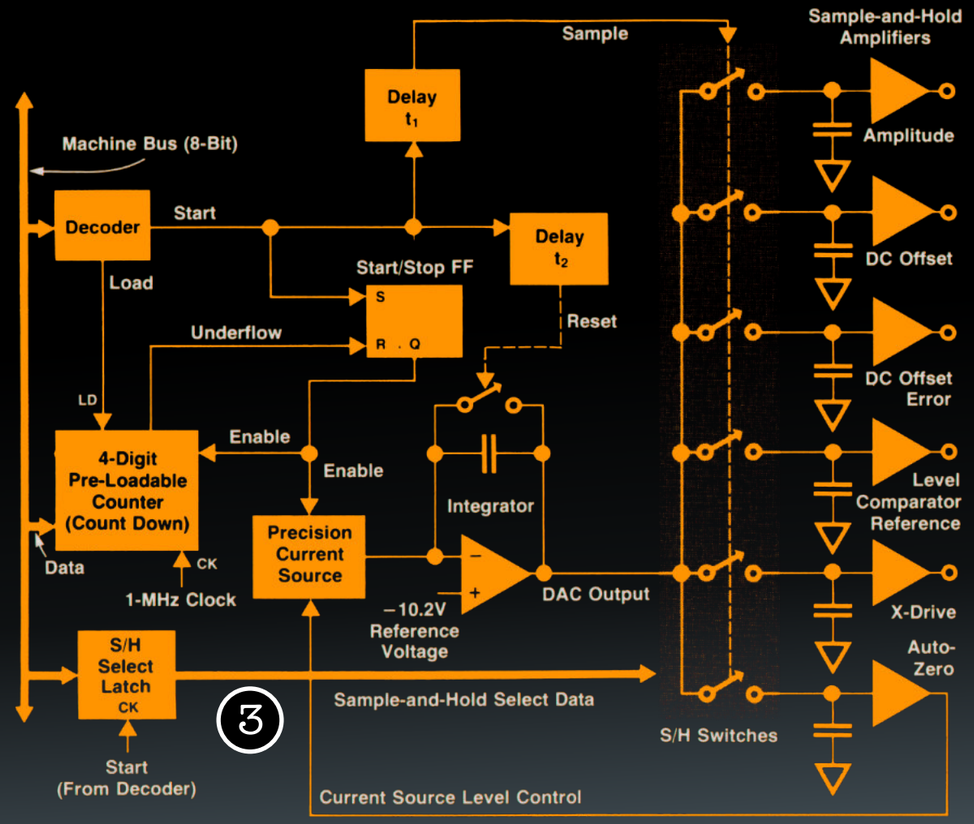
The DAC itself

Today, most microcontroller have one or more DAC output. At the time, the DAC had to be implemented with discrete components. The heart of the 3325A’s DAC is the integrator. It ramps up from a known voltage level at a rate fixed by the precision current source for a period of time determined by the pre-loadable countdown counter. The clock frequency and the number loaded into the counter thus determine what the integrator voltage level will be at the end of the ramp.

Each conversion requires approximately 1 ms:

- the microprocessor controller loads a four-digit BCD number N, corresponding to the desired output voltage, into the counter;
- the integrator is reset and the counter and the precision current source are enabled simultaneously;
- when the counter reaches 0 after counting down N clock pulses, the current source is disabled and the integrator holds the output voltage directly proportional to N.





❶ DAC output (above) and relative sync pulse (below)

❷ The test points where to pick the above signals for the oscilloscope

❸ The e-Verniers system general block diagram

Six controls

The DAC continuously produces six output voltages, one by one. Six analog switches connect in a specific moment the DAC output to a specific Sample & Hold circuit, which will store this value until the next cycle; in consequence, the entire cycle requires 6 ms.

In photo ❶, you can see the DAC output signal; the yellow arrow point, for example, to the sine amplitude pulse. If you select AMPLITUDE and press the UP and DOWN keys on the front panel, you can see that pulse raising or lowering in accord.

Photo ❷ shows where to pick the signals for the oscilloscope: the DAC test point and the AZ, where you find the signal shown in the lower waveform, which identifies the start of the DAC cycle.

Amplitude Loop

Following our description, we are now in possession of the sine frequency generation (we will see later the other waveforms) and the e-Verniers. Let's now see how the output amplitude is controlled, underlining since now that the 3325A is still today a very precise instrument, not only in frequency, but in amplitude as well.

On the 30 MHz Reference

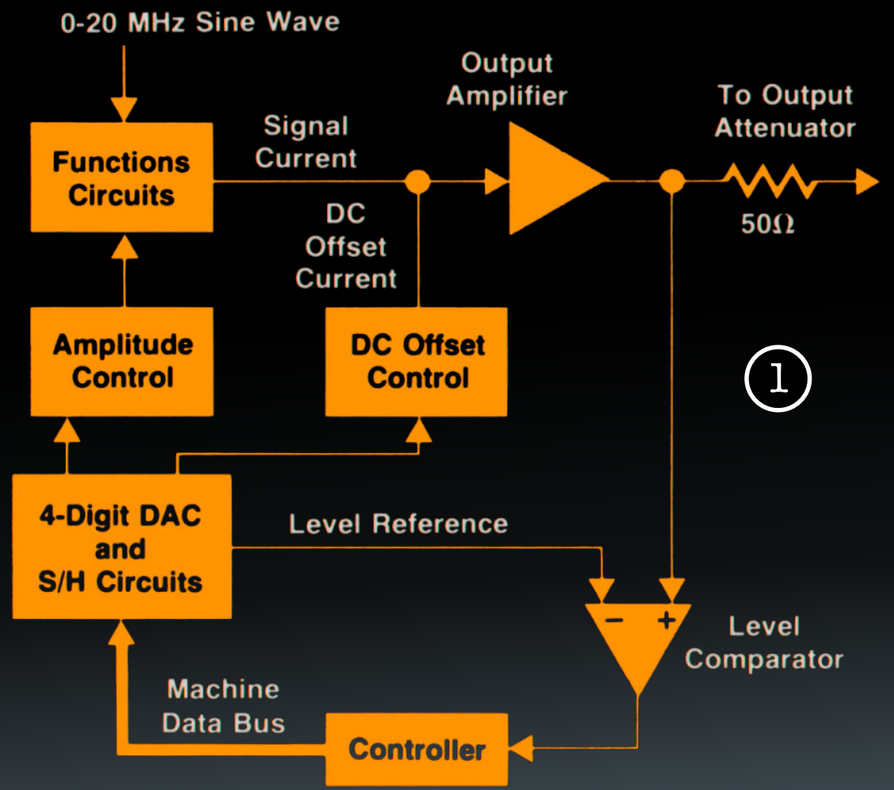
The **output amplitude** is obviously set by an output programmable attenuator, but its fine control is performed acting on the 30 MHz Reference signal, unexpectedly from my point of view; I thought it should be done on the signal outputted by the Mixer, even if I don't know why. I discovered this by myself, because it is not clearly highlighted in the manual.

The interesting TP4

As you can see in the manual figure 8.40 (Service Group G), IC A3U1 receives the SINE AMPLITUDE signal from relative e-Vernier (via J23), multiplies it times an external modulation (if any), and drives A3U13, which controls the current with which the 30 MHz signal is sent to the mixer. On the output of A3U13 there is a very interesting **TP4** test point where a DC voltage is present, proportional to the required output amplitude. We will talk about it soon; for now just remember that you can see here a voltage proportional to the expected output level.

Closed loop

Using the SINE AMPLITUDE e-Vernier, the output amplitude can be set by software. But this control loop is normally closed, i.e., the software can also determine the output level and so decide to correct the output level. In other words, using a peak detector, the processor is able to sample the DC offset and amplitude of the signal at the output of the Output Amplifier, and compensate for errors by correcting the e-Vernier setting (see figure on the right).



❶ The amplitude control loop

Auto calibration

A routine for calibrating the output amplitude and offset levels is executed whenever the instrument is turned on, whenever the output function is changed, whenever the AMPTD CAL button is pressed, and whenever an external controller transmits a device clear or an amplitude calibrate command.

Auto Calibration Disable (ACD)

When servicing the amplitude control path, the closed-loop control could make impossible to understand what exactly is happening, so a way to disable auto-calibration is provided. This operation mode is activated by tying the ACD test point (on A14, see the photo on the right) to ground. This breaks the loop by preventing the processor from performing subsequent Auto Calibrations. After tying ACD to ground, cycle power off, then on, to erase from RAM all previous Auto Cal information.

Warning: HP changed the name of some boards in the time; so, in the above said figure 8.40, they say that the input to the multiplier comes from A4J5, not present in the manual. The true board is A14 and the connector J24.

Using TP4

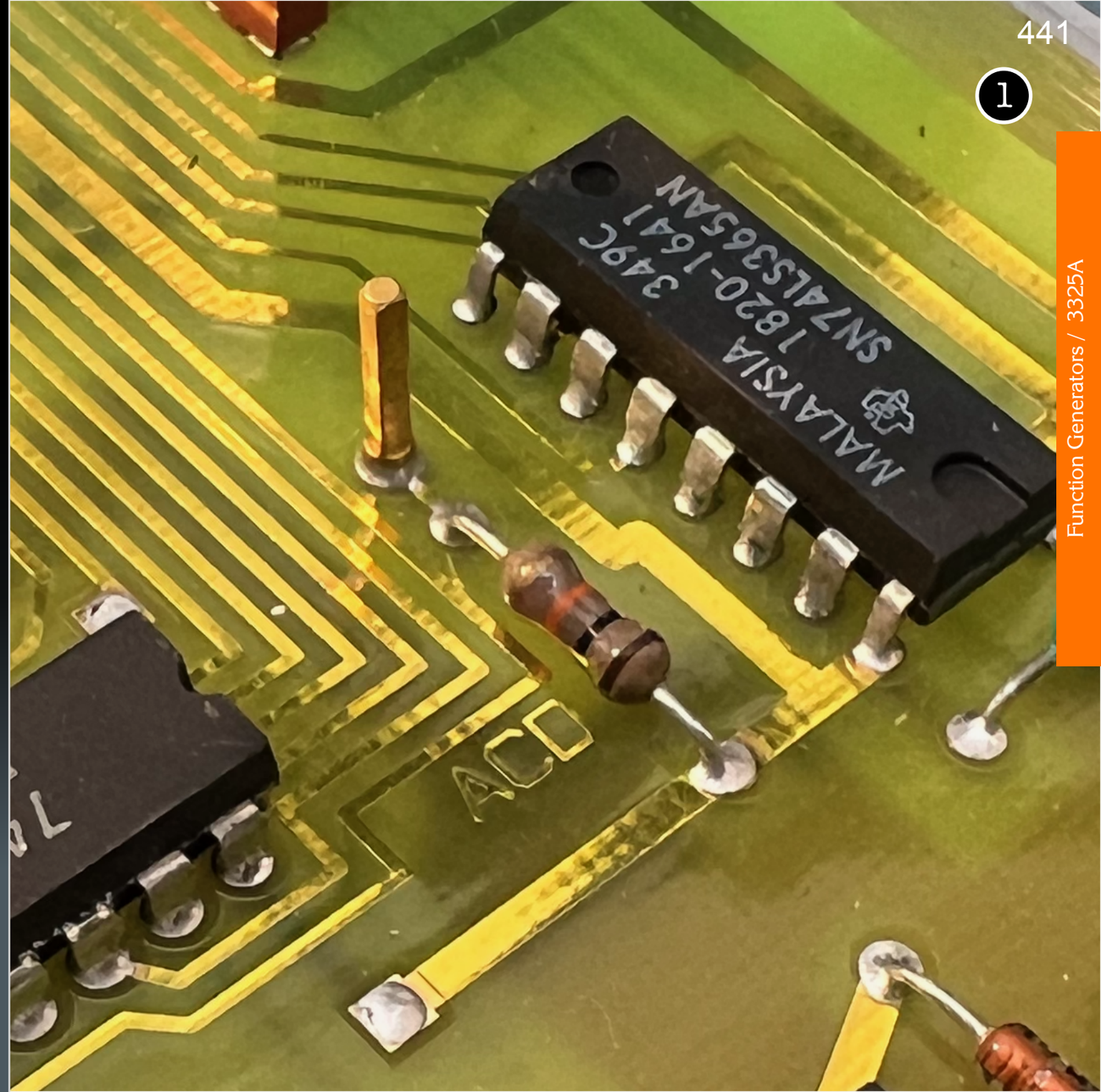
You can use TP4 to understand if the output amplitude control operates correctly in this way:

- connect the oscilloscope or a voltmeter to TP4;
- using the front panel, set the signal amplitude to a certain value (e.g., 5 V), and then use the UP and DOWN keys change it;
- if everything is OK, the value on TP4 should change accordingly.

If not, switch off, disable the ACD by strapping to ground the ACD test point as described above, switch on again, and repeat the above test. If now you see that TP4 follow the commands, the problem is somewhere in the amplitude loop; otherwise check the DAC and the amplitude analog switch.

In my case, TP4 was at zero volt, but with ACD it became active; the e-Vernier was OK and the problem was in the amplitude loop.

❶ TP4 test point is marked ACD on the PCB.



Not Only Sine

To deserve the name **function generator**, a good guy must be able to produce not only sine waves but also (at least) square, triangle and ramp signals. Today, most instruments of this type can produce "arbitrary" waveforms, but, at the time, we had to settle.

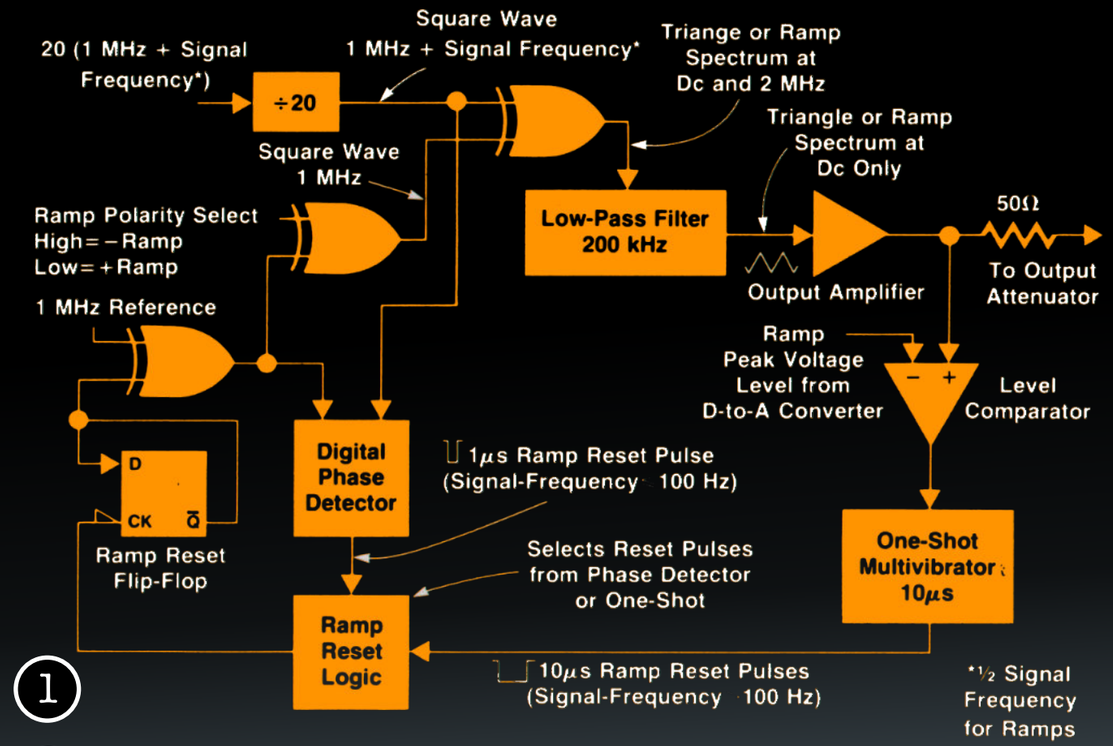
This task is performed by the 3325A Function Circuits which provide the proper current to the output amplifier for each function. It includes a number of current sources, and the circuits which develop the square wave, triangle, and ramp functions from the sine wave. Function switching is accomplished by the enable signals shown in the block diagram. Faults in this area are covered by Service Group J.

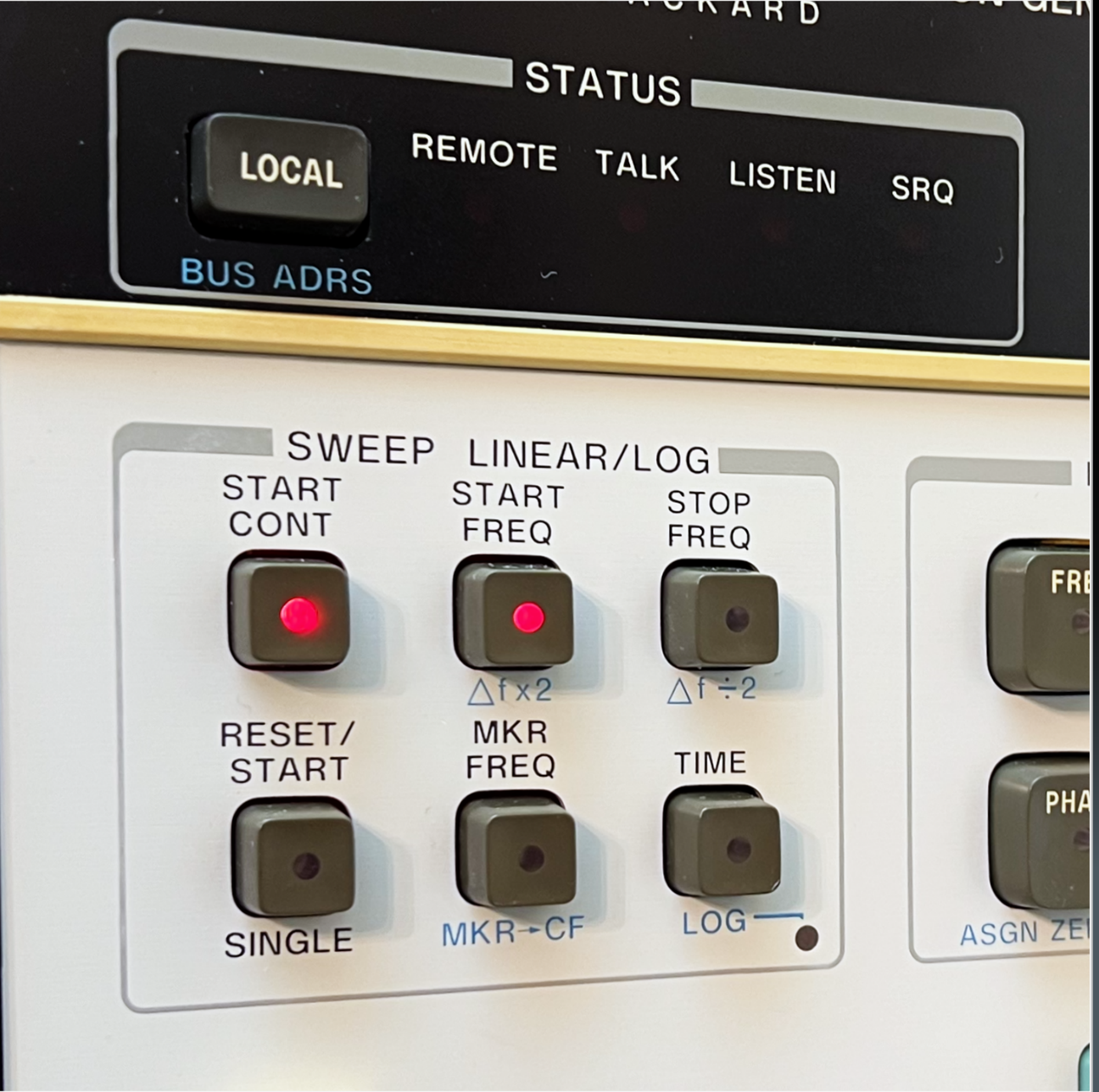
Sine Wave - We already described this function, the amplitude control and how the sine wave from the mixer passes through a current amplifier to the output amplifier.

Square Wave - The sine wave input is sent through a squaring circuit (Q101, Q102, U31) and then divided by two (U33) to produce the square wave output. Consequently, in the square wave function, the sine wave must be twice the output frequency, and maximum output frequency is 10 MHz; the choice of this double frequency value is automatically performed by software.

Triangle and Ramp. I was curious to know in which way the square wave was produced, and rightly so, because the circuit is very interesting. The idea is to produce a frequency equal to the desired frequency (e.g., 10 KHz) plus 1 MHz, and phase compare it to a 1 MHz reference in an exclusive OR gate. Because the output of the gate is high when one and only one input is high, the gate output is a series of pulses whose width varies in proportion to the phase difference between the two gate input signals (figure 2). The gate output drives a current amplifier and the resulting current pulse signal is sent through a filter which shapes the triangle. Other circuits and software adjust the generated frequency as indicated and manage the housekeeping details.

❶ 3325A Function Circuits simplified block diagram.
❷ Generation of the triangle wave by mean of XOR phase comparison to a reference square wave.





Sweeping

Frequency sweep

An important addition to a function generator is the possibility to automatically vary the frequency of the signal over a certain range at a constant amplitude, feature normally called **sweep**. This is normally used to determine the behavior of a component or a circuit, like, for example, the frequency response of a an amplifier or to help tuning the IF stage of a radio receiver. I also needed something like that designing contactless antennas for smart card readers, and used a Spectrum Analyzer with a Tracking Generator to do that.

3325A features

The 3325A has the sweep possibility, with some improvements over the old generators:

- a **wideband** sweep;
- there are **no phase discontinuities**, usually associated with synthesizers. Sweep is phase continuous over the full frequency;
- range of the main output.

The user has control of the **start** and **stop** frequencies, choice of **linear** or **logarithmic** sweep, and **sweep time**. The linear sweep has single-sweep and continuous-sweep modes with sweep times between 0.01 and 100 seconds. Total sweep times for single log sweep range from 2 to 100 seconds or 0.1 to 100 seconds for continuous log sweep. **X-DRIVE** and **Z-BLANK** outputs are provided for driving CRTs and X-Y recorders. Also available is a TTL-level **MARKER** output that changes state during a linear sweep when the output frequency passes through the selected marker frequency. Logarithmic sweep is approximated by a succession of linear segments. A new frequency increment is loaded 10 times per decade during single sweep. Convenient "zoom" functions AFx2 and AF÷2 to quickly change the frequency span are supplied.

How does it do?

Phase-continuous frequency sweep of all functions was made possible by the addition of another register and BCD adder-subtractor to the count-by-O.F section.

A frequency increment stored in this register is added to the F register during each reference period to cause the frequency to sweep up. Sweep down is accomplished by subtracting the increment.

Fixing the 3325A

The 3325A manual is probably one of the best ever. For once, it seems having been written by someone from the maintenance service and not only by the technical dept., and contains many practical suggestions. The matter is divided in Service Groups, and, for each group, also the board layout is reported, with the non-interesting areas shaded (BTW: if you want a good quality manual, buy it from **Artek Manuals**). Anyway, IMHO, two thing lack in it: a shorter general overview and some waveform in the instrument's key points. To remedy, I tried to supply you these parts.

Easy to work on

With the 3325A, we probably enjoy a particular situation that makes the repairs easier. The world was used to big and heavy equipment, so a size reduction was not yet convenient, and probably there was the risk to make the instrument reduced in its perceived "importance". So a certain space waste was accepted in the design. That for us is precious, and makes easily accessible almost every component, either for checking, either for replacing. If we add the clean and linear circuit design and a good manual, you get one of the best serviceable instrument in absolute.

Urgent questions

When you bought a non-working 3325A, your more urgent question is to define the fault boundaries. Did I purchased a scrap or a repair is possible and probable? So here are my suggestions for a basic and quick analysis.

Power supply

Surely, you don't need this suggestion, and the power supply is usually the first check. Strangely, the power supply is described in Group O (not 0 zero, O like Ontario), which is the last in the manual. Three voltages are used: +5V, +15V and –15V, each of them has a test point on the A2 Power Supply Board.

IMPORTANT: the negative is not grounded, or better, it is grounded only on the internal frames. So don't strap your negative probe to the outer frame….



OUTPERFORMED!

When repaired, I enjoyed with some crossed tests. In one of them, the old 400H voltmeter outperformed the more modern 3403C in small signals measurement. You can see here the h400 measuring a 400 uV RMS sine wave produced by the 3325A. Even its precision is definitely good (the H400 and the 3325A say almost the same values).
The 3403C gave up at about 1.7 mV.

Fault types

Obviously, many type of faults are possible, but most of them can be traced back to some basic types:

- **dead**: nothing is shown on the display;
- starting but with **OSC FAIL** message: the problem is likely in the frequency synthesis area;
- starting but with **A-CAL FAIL** message: the problem is likely in the amplitude control area or in the amplification chains.



In the case of A-CAL, pressing the SHIFT/SELF TEST button, you will get also three possible FAIL n messages; n says if the problem is with the sine wave (1), the square wave (2) or the triangular one (3).

My case was A-CAL with all the three FAIL 1, FAIL 2 and FAIL 3. My wish was to understand the boundaries of the fault. Your case might be different, but I hope that the information contained in this section of the book can however be useful for the first aid.

Checking the 30 MHz

The 30 MHz reference is the heart of the instrument: all the frequencies are based on it.

Before affording Service Group G, you can quickly check if the **REF OUT 1 MHz 0 dBm** signal on the rear panel (see figure). If the signal is OK, the 30 MHz zone is probably working.

You can also easily check if the 30 MHz oscillator locks to an external reference signal: connect an external signal generator to the **ETX REF IN 1,10 MHz >0dBm** BNC on the rear panel, and produce a 10 MHz signal above 0 dBm. The EXT REF annunciator of the front panel should light. I used the 10 MHz Reference Out from the 8568B Spectrum Analyzer and it worked perfectly (later I investigated more this point, discovering that without any adjustment, the 3325A frequency is only 1.5 Hz out relatively to the 8568B, with a very low drift, probably due to the 3325A which, in my case, has not the Option 001, i.e., the oven oscillator. For me it's enough.

❶ The error message produced by my 3325A when arrived
❷ Simplified block diagram and signal accesses from the rear panel.

Checking the synthesizer

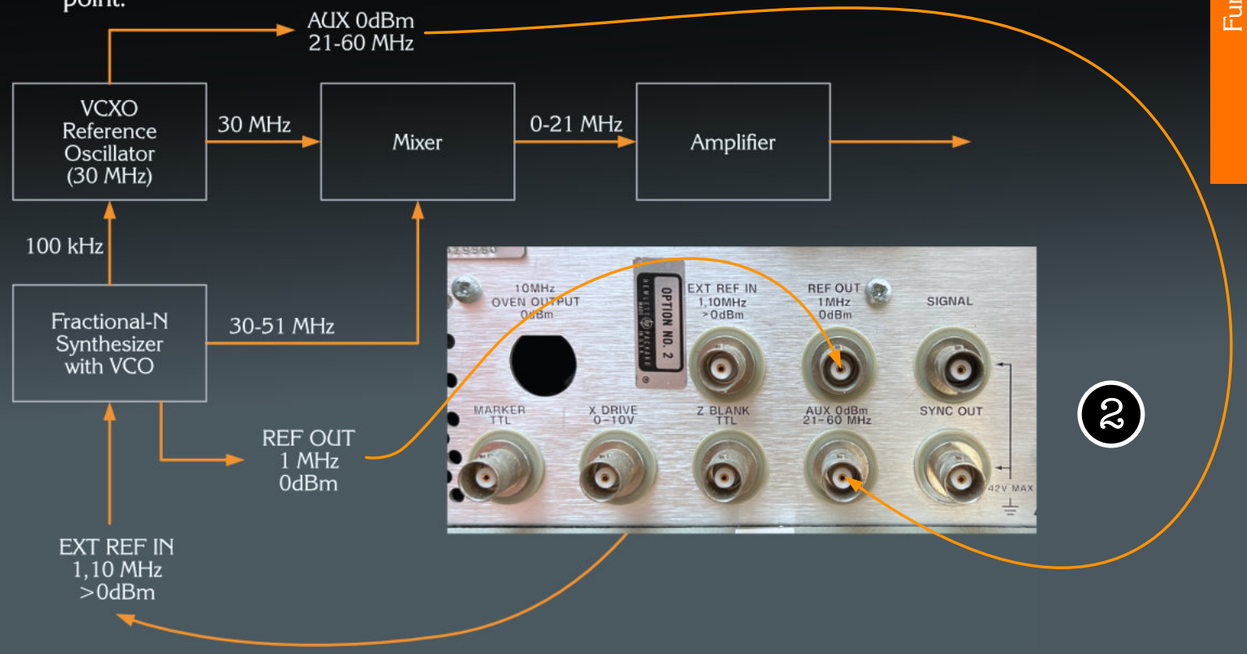
Now you can check the synthesizer signal. To do that, set 3325A's frequency to 21 MHz from the front panel and connect an oscilloscope to the **AUX 21-60 MHz 0dBm** rear panel connector. You should get a signal, approximately a square wave, at 21 MHz. The synthesizer was described above and is covered in the following manual's Service Groups:

- Service Group D - Voltage Controlled Oscillator Shield;
- Service Group E - N.F Counter;
- Service Group F - Fractional N Analog Circuits.

Checking the D/A Converter

See the notes above ("e-Verniers) and refer to Service Group I for the D/A Converter and Sample & Hold. Disable the ACD and try to move the TP4 voltage by using the front panel AMPLITUDE setting.

From what I found on the Internet, faults in the analog switches that link the DAC output to Sample & Holds are one of the most frequent 3325A problems. Several videos on YouTube are related to this point.



Checking the Mixer

The Mixer (Service Group H) receives the 30 MHz signal from the Reference Oscillator and the 40 MHz signal from the Synthesizer, when a frequency of 10 MHz is programmed. To check its operation, proceed as follow:

- switch the power off;
- strap to ground the ACD test point;
- switch the power on;
- program 1 MHz with 10 V amplitude;
- check the signal at A3TP6: you should find a sine signal with about 200 mV p-p amplitude, at the frequency of 1 MHz;
- check also A3TP7, the measured voltage should be the same as A3TP6.

From this point on, there are the final amplifier, the attenuator and the level comparator (Service Group K - Output Amplifier and Level Comparator).

The repair

Following this procedure I found the problem in my 3325A: the IC U3U15 CA3127E was broken. The signal was as prescribed on TP6 but completely disappeared on TP7. I replaced that chip with a socket and ordered it new chip on eBay (it can be found easily), and paid something extra for a fast delivery: I couldn't wait to see the result. Don't confuse U3U15 with A14U15 CA3046, which has a very similar symbol in the schematics, as I did.

In the meanwhile, a replacement A3 board that I had found on eBay for a good price arrived unexpectedly fast. I replaced my A3 board with this, and the 3325A eventually passed all the tests. But that was a too easy victory: I wanted to see if **my** diagnosis and **my** cure were correct.

When two days later the new 3127E chip arrived, I replaced it, and this time it was pure joy: the 3325A was repaired and was back to life! Easier than I expected.

BTW: at the same time of the 3325A, I bought the 8012B that you can find described also in this book. I expected a long fight for the first and a quick victory for the second. It was the contrary, and not by chance; the infinitely superior 3325A, albeit infinitely more complex, was designed for maintenance, and its manual was much more detailed. The times were changing also on this front.



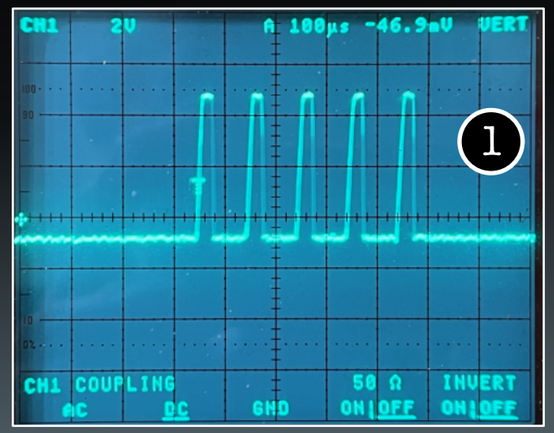
The A3 board with the U15 chip replaced by a socket (circled in red), ready to accept) the new 3127E which was arriving.

Cooperation

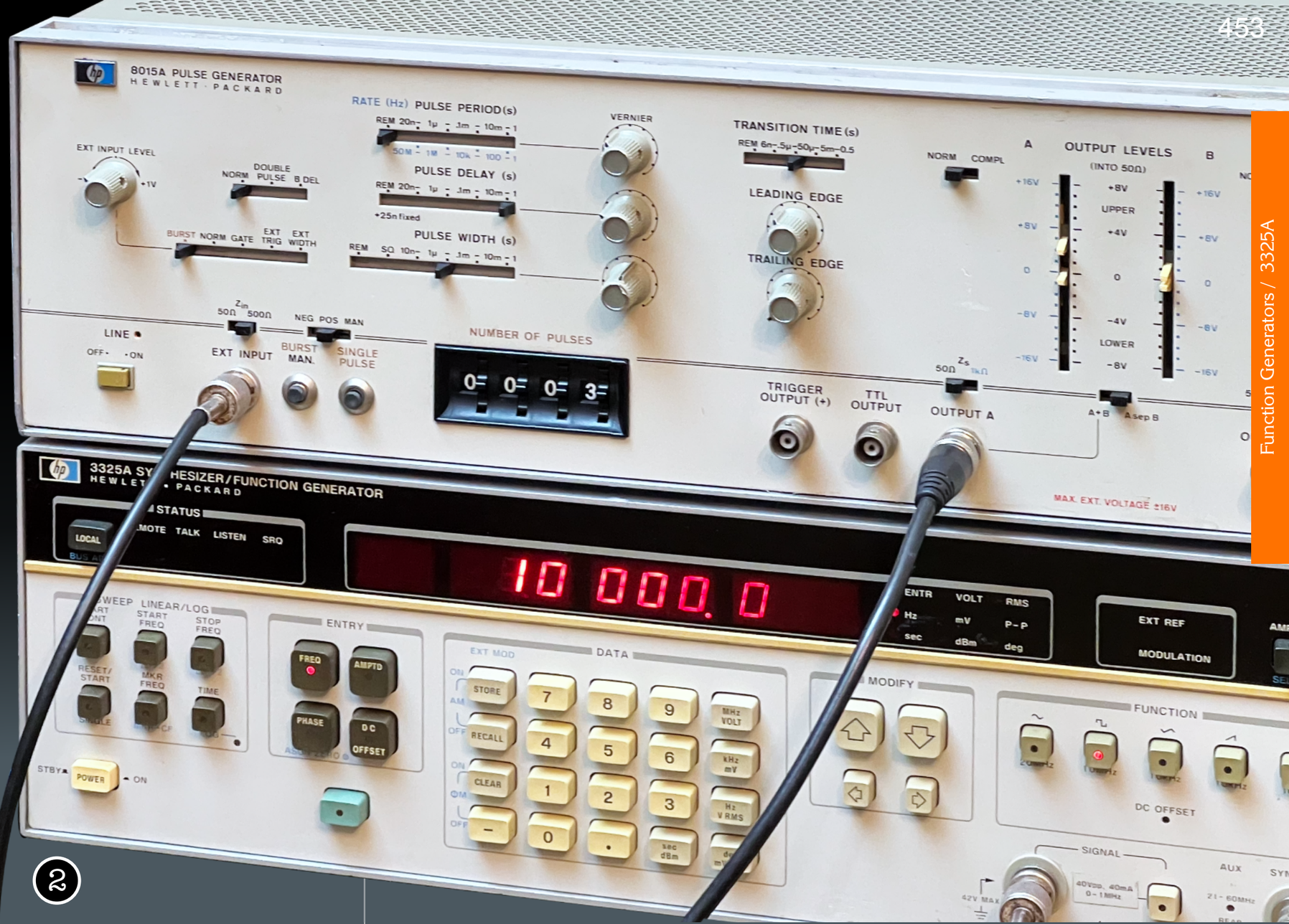
The experience with the 3325A induced me to slightly change my point of view about the old 8000 analog pulse generator series. The 3325A is still today a very precise instrument, but it is only a function generator, not a pulse generator.

For example, the 3325A can only produce a square wave, and the pulse duration cannot be modified like with the true 8000-Series pulse generators. In addition, the transition time cannot be modified, nor pulses trains are possible.

So I enjoyed joining the 3325A with the 8015A, so that the two friends could compensate each other. In the photo below a 5-pulses train with an evident slope on the trailing edge, possible with the 8015A. What a lovely couple!



❶ The pulse train produced by the 8015A has slower leading edges.
❷ The two instruments have the same front size, but the 3325A is much deeper. Too bad that neither of them has the beautiful and expensive handles; both of them had the rack kit that I regularly remove, because they make the instrument larger and are even a little dangerous.

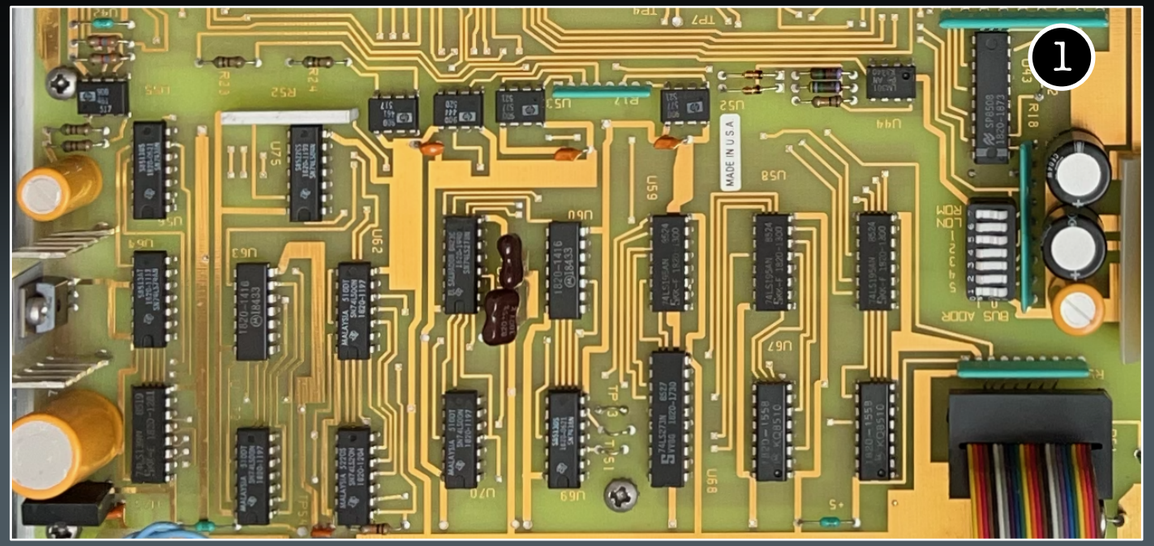


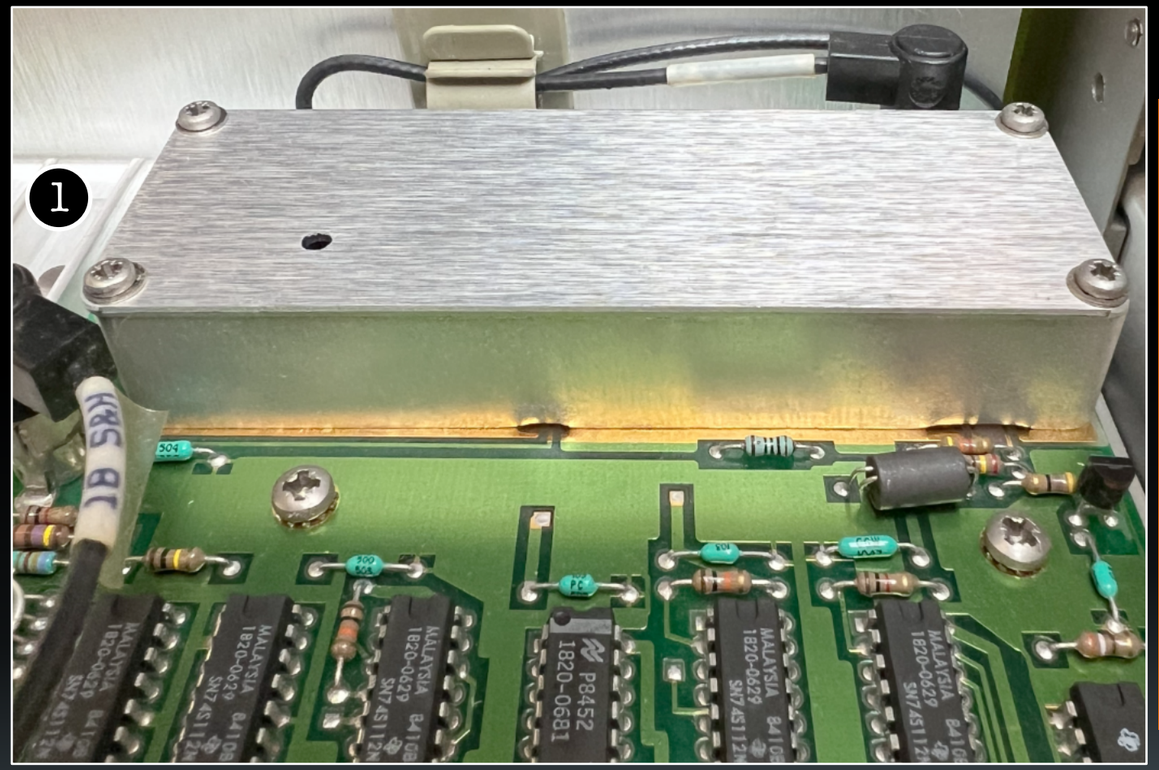
Last Notes

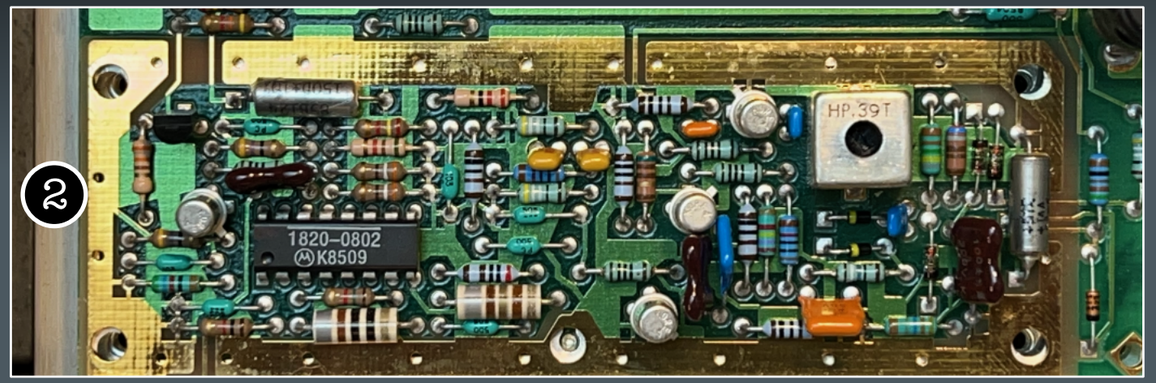
❶ **HP-IB** - All of the operations of the 3325A may be controlled through the HP-IB. As a convenience feature, the instrument's HP-IB address is displayed when the BUS ADRS button is pressed. As evident in the photo below, the HP-IB hardware is optically coupled to the function-generating hardware to provide ground-loop isolation.

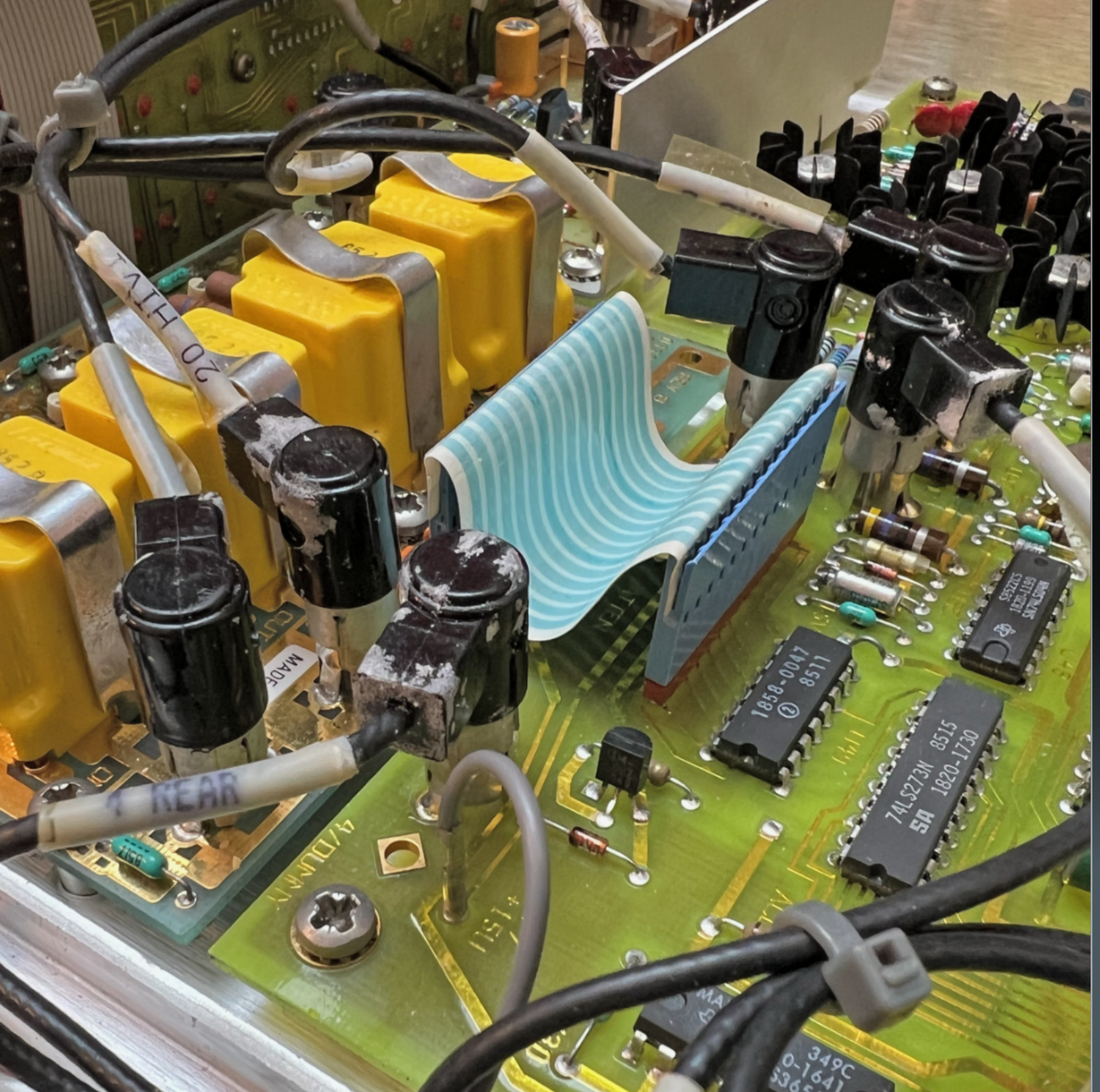
❷ and ❸ **Mechanical Construction** - Unusual in a synthesizer, the 3325A was designed with an open layout that makes the instrument easy to assemble and service, as already mentioned. This also allows the components to remain cool, thereby improving reliability. Too bad for the noisy fan, a true tornado that I strongly feel when working in front of the equipment. The only shielding required is for sensitive analog circuits in the VCO and the sine wave mixer. This is done with low cost extrusions that attach to the main circuit board (in the photos, the VCO, with and without the shield).

Signature Analysis - Servicing was also simplified by designing the controller for digital signature analysis. Strange: for many years I never heard of it any longer; now I had two consecutive restorations which relied on it (the other is the 7D20 digital plug-in described in the 7000-Series Tektronix e-book).









Conclusions

The 3325A is, together with the 8640B Signal Generator and the 8568B Spectrum Analyzer, one of the **Very Important Gears** (VIG) described in this book, instruments that were among the absolute top at their time, still nowadays re perfectly usable, and even with some advantages. For example, I find much more comfortable their keyboard-and-knobs-based user interface than many modern touch screens (by the way: my new car replaced many switches and buttons with a touch screen; when I enter a tunnel, I should navigate in three-level menu to find the air recycle - slow and dangerous… we are getting mad).

In addition, the 3325A offered me the opportunity to study the Fractional-N PLL that I didn't know and that represented an important step forward in signal generation.

I wish to close with a last tribute to its extreme serviceability with the photo on the left. Most of the boards are very fast to remove, with just one digital connector and many signal cables with pull-able connectors at both ends, which make tests very easy and straightforward, thanks also to each cable clearly identified.

The 3325A is a true VIG, thanks Hewlett Packard!

Signal Sources

Subsection

Some Comparisons

A Road Test

Comparing Produced Waves

After having described several Signal Sources, let's now perform on them some tests to see if they confirm the expectations you could have based on what we said, in particular related to the evolution of signal generation techniques.

We take in consideration three models:

- the 8640B as **Full Analog**;
- the 8165A as **Integer-N PLL;**
- the 3325A as **Fractional-N PLL.**

Just as a reference, we added the good Marconi 2022E, at least ten years more recent. Tests have been performed with the Advantest R3132, also described in this manual, and the 8568B Spectrum Analyzers.

Phase Noise @ 20 MHz.

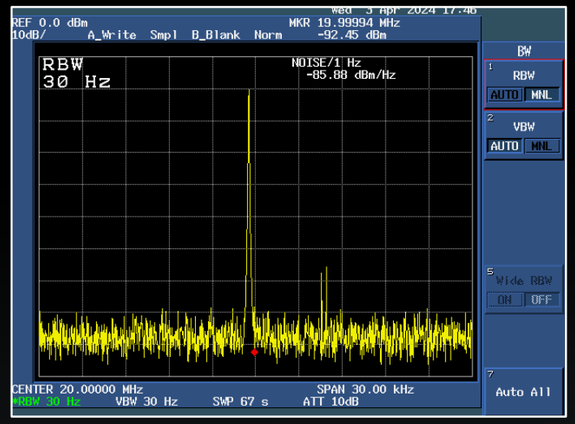
The first test is related to Phase Noise @ 20 MHz with 30 kHz span, as HP uses to do. We will introduce the Phase Noise concept later, talking about Spectrum Analyzers. For now, we say only that describes in the frequency domain the phase stability of a signal (i.e., the jitter in the time domain). Higher the figure, better the generator. The ideal generator has this value equal to infinite, and is represented on the frequency spectrum like a vertical line of zero width.

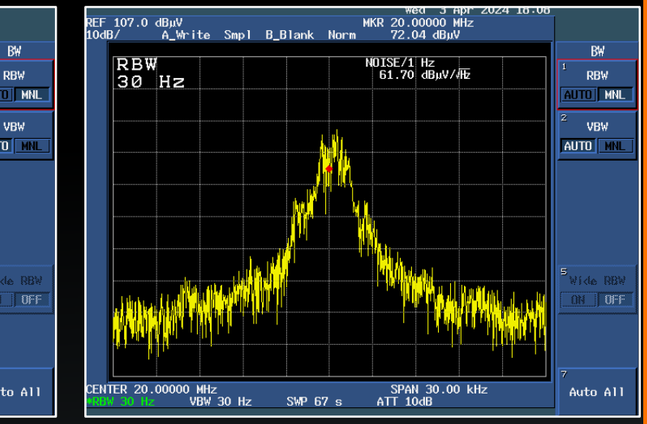
The 1972 8640B, full analog, was highly respected for its signal purity and has a very good PN of 85 dB/1Hz. The 8165A, as we forecasted, due to Integer-N PLL, stays worse for almost 25 dB/1Hz. Very good the 3325A, only 5 points below the 8640B and better that the very good Marconi 2022E. The Fractional-N Synthesizer confirms to be a great find.

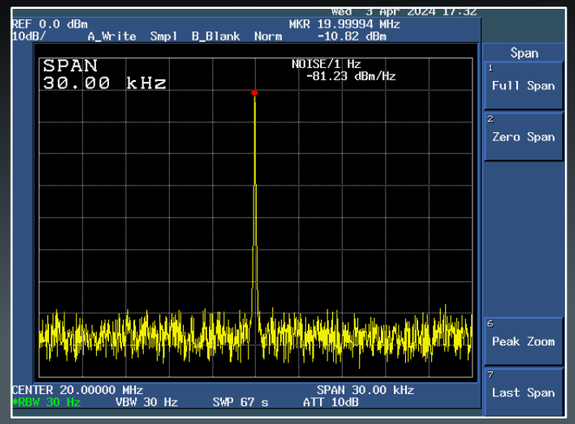
Phase Noise @ 1 MHz

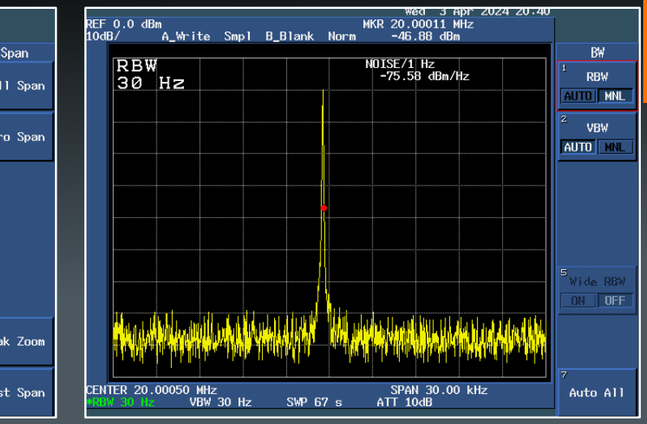
I repeated the tests @ 1 MHz (span 30 kHz), with similar results. The amazing 3325A becomes the best, even if slightly.

Phase Noise @ 20 MHz







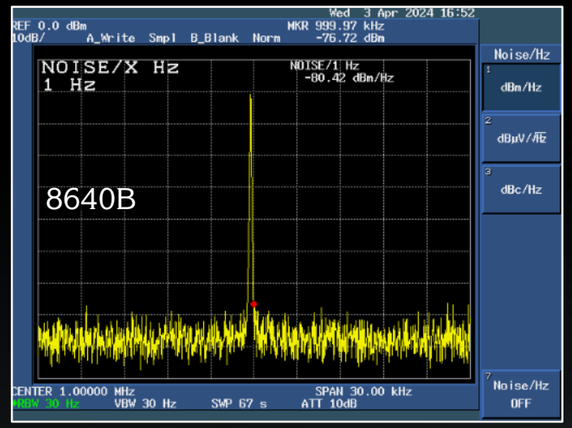


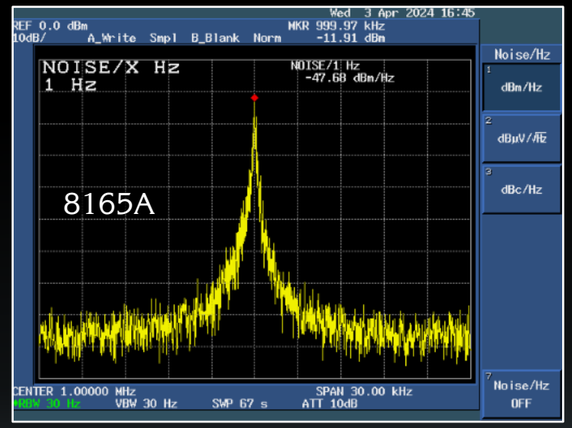
Spurious harmonics @ 500 kHz

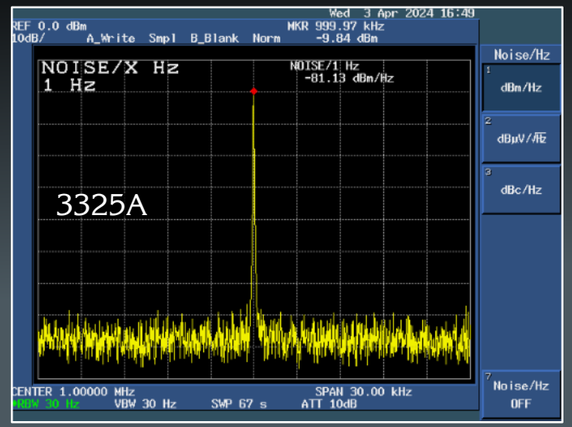
In this case we tested the presence of unwanted harmonics of a 500 kHz carrier. The 8640B specifications say that harmonics are “less than 30 dBc”; here they are numerous but 50 dB lower, so nothing to blame. The 8165A confirms to be the worst, but not so much as I though, so I repeated the test (you can see a different date) but the performance was confirmed. The 3325A tears up everyone else, with an astonishing -60 dBc, i.e., the second harmonic is 1,000,000 times less the fundamental. Even the Marconi could not do better.

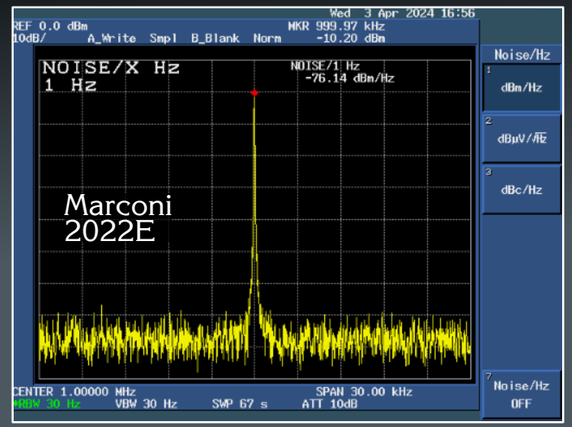
Fractional-N Wins

Phase Noise @ 1 MHz

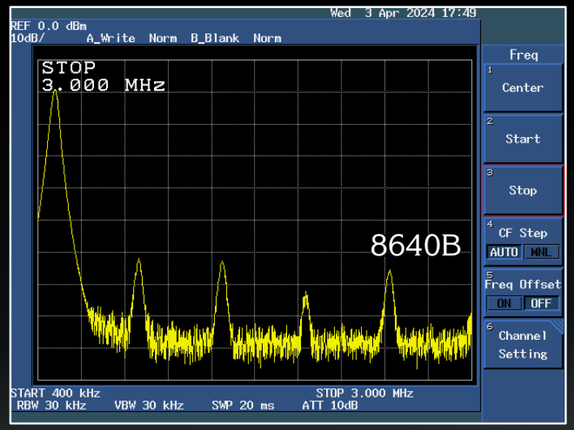


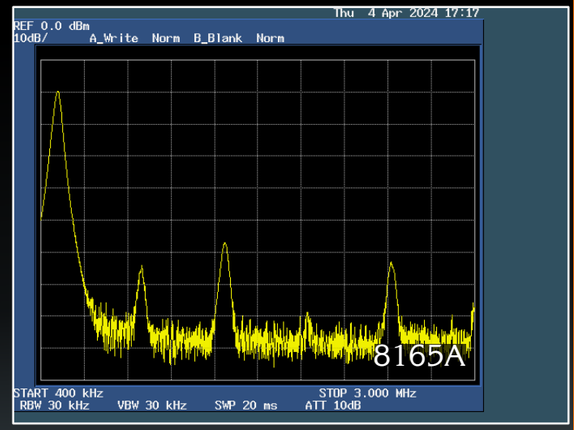


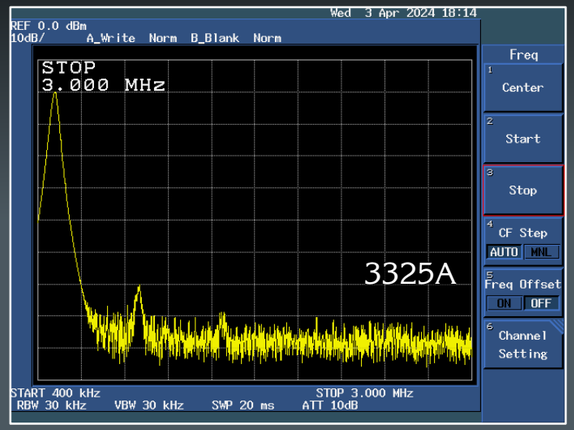


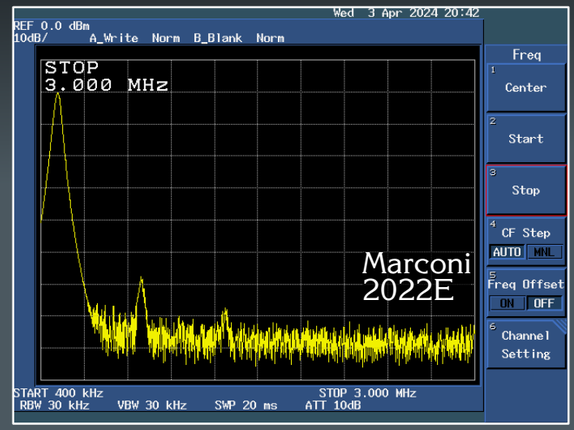


Harmonics @ 500 KHz









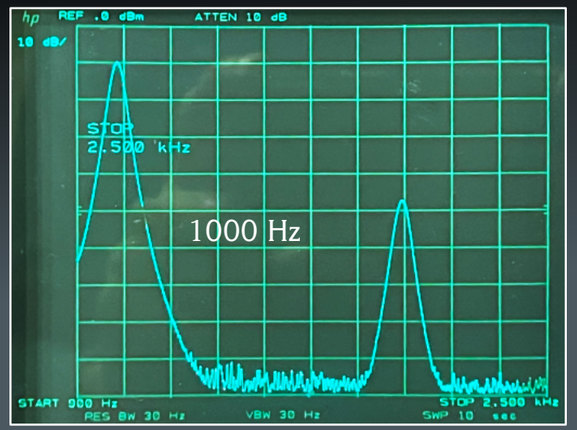
8165A Dual Mode

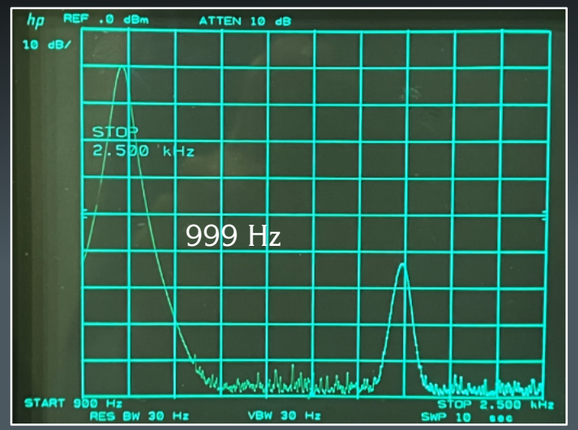
As we saw, the 8165A has two different operation modes; below 1 kHz, it uses a completely different approach to generate the output signal. So no wonder that 1 Hz less shows a relevant difference in the produced spectrum: the DAC based synthesized sine 2nd harmonic is nearly 15 dB lower. For this test, I had to pass to the 8568B, because the 3132 stops at 9 kHz (downward). The 8568A does not compute automatically phase noise, but from the plot it seems rather similar in both cases.

Conclusions

Note that tests could have been influenced by the preservation state of the equipment or simply by a different calibration. However, I believe that the excellent results of the Fractional-N PLL were rather evident, even more than expected, while the pure-PLL solution offers a good frequency accuracy but is definitely noisy.

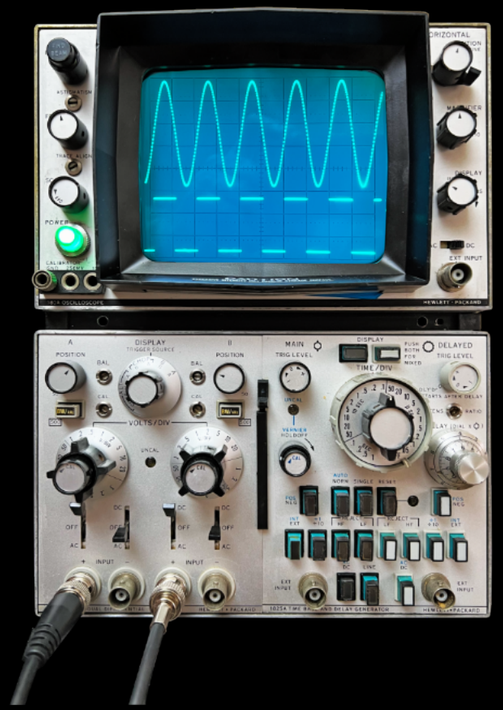
8165A Harmonics @ 1 KHz







Fixing this 8160A board was exhausting...



Section:

Oscilloscopes

Subsection:

180A Oscilloscope

The forerunner of many other oscilloscope families, not only from Hewlett-Packard.

180A Oscilloscope

Perspective Evolution

From time to time, when I analyze a new piece of equipment, I understand something more that makes me to change my previous beliefs. In my book about the Tektronix 7000 Series [2], I wrote rather superficially something about the HP 180, which we are going to delve into here in a more detailed manner. I find this process exciting, because it offers me the opportunity to investigate interesting matters.

The opportunity to talk about the 180 Series was offered to me by the Marzaglia market, which we talk about from time to time, where I went with my friend Francesco and where I could get two mainframes (180A and 181A) and two plug-ins (1825A and 1806A) for only 40 euros. They looked like scraps, but eventually were not too bad, as we are going to see.

Who Had the Idea?

I have to admit that, as we are going to see, things were exactly the opposite of what I had imagined: it was not HP which tried to follow Tektronix, but it was Tektronix to follow most of the concepts introduced by the ingenious 180 Series, arrived three years before in 1966, and described in the August 1966 issue of the HP Journal.

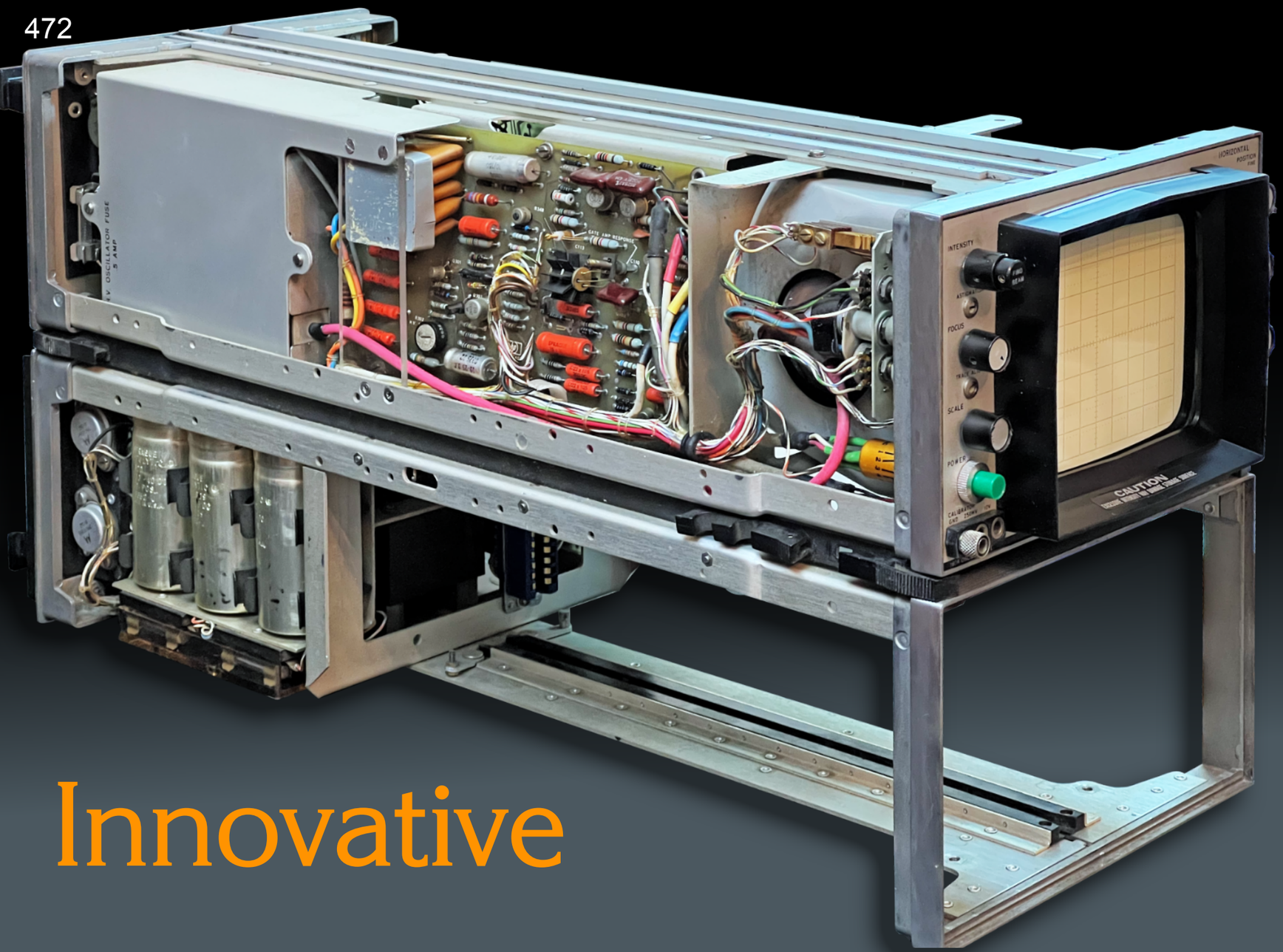
At that time, Tektronix had nothing similar; the 546 had the same 50-MHz bandwidth of the 180 and one vertical plug-in, but was still based on vacuum tubes and was incomparably bigger and heavier.

At the end of 1969, the 7000 Series was not only to close the gap, but also to mark distances with all the competitors.

But let's return to 1966, and enjoy this appetizing novelty.



HP180A Oscilloscope



Innovative

Light and Flexible

As we told, in 1966 a 50-MHz plug-in oscilloscope was big and heavy (even if Tektronix offered wonderful portable, non-plug-in machines, like the 453).

The new 180A was really innovative: fully transistorized, it had a nicely large CRT, but was small and light (9.9 kg without plug-ins), with a “large” display (8 x 10 cm) (the portable 453 weighted 14 kg and its CRT was only 4.8 x 6 cm).

Differently from the large 546, in the 180A the time base was plug-in as well, allowing to save money if you were not interested into the dual time base.

The initial 50-MHz bandwidth was going to be improved to 100-MHz, but without technical variations, I believe. Probably, it was achieved just with better plug-ins, which included also the final vertical amplifier directly linked to the CRT.

Prices

In 1967, a 180A mainframe was quoted at $825, i.e. near $8,000 in 2024. The 1806A dual channel, differential input amplifier for low level measurements arrived later and in 1971 cost $675, i.e., $5,234 in 2024. The 1825A time base and delay generator, in 1975 catalog was at $850, near $5,000 in 2024, thus bringing the total price of the configuration depicted here to an equivalent of about 18,000 USD today.

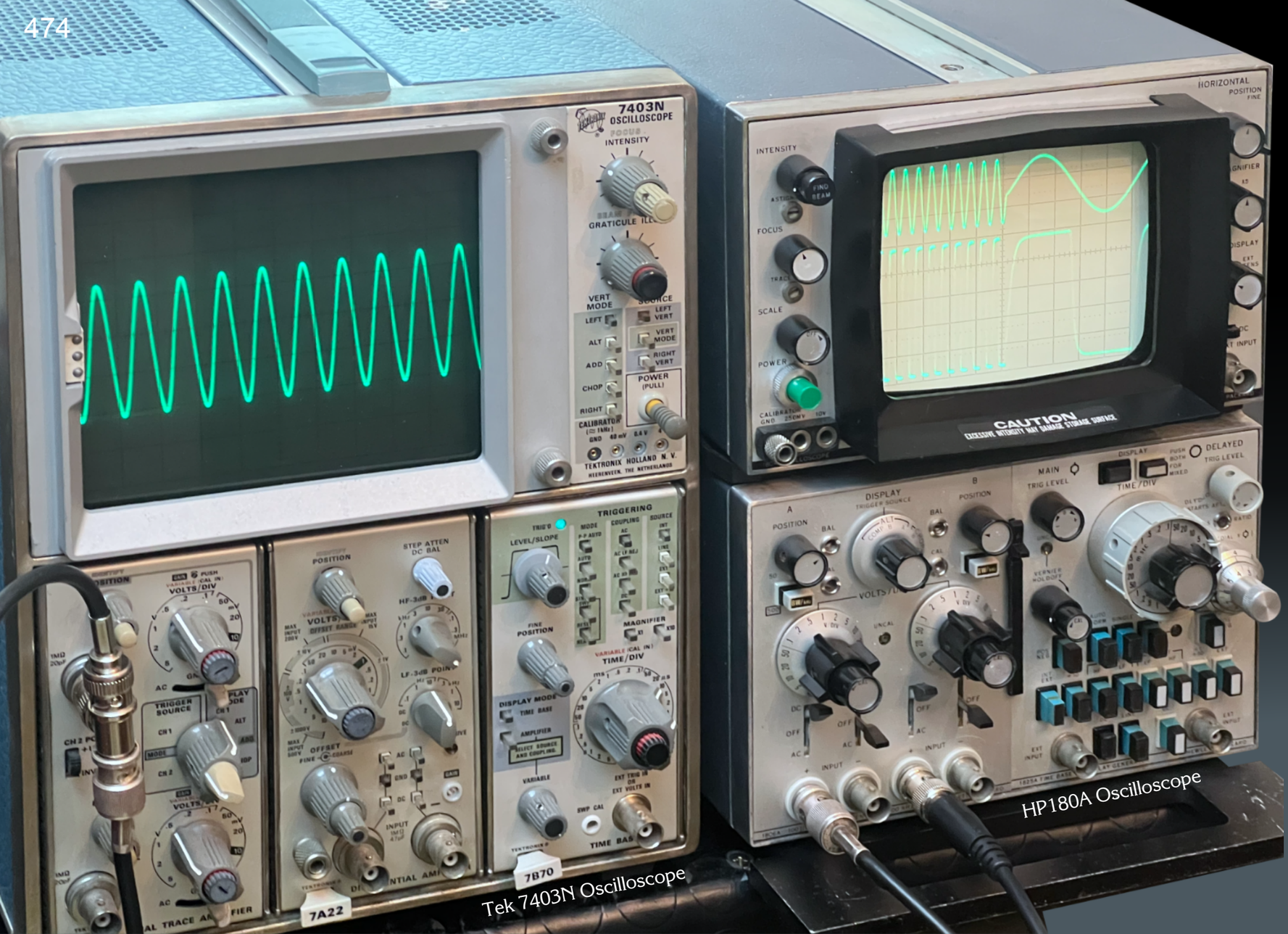
The CRT storage 181A, which we will examine next, was much more expensive, and, alone, it cost $2,215 in 1975, or $12,930 today.

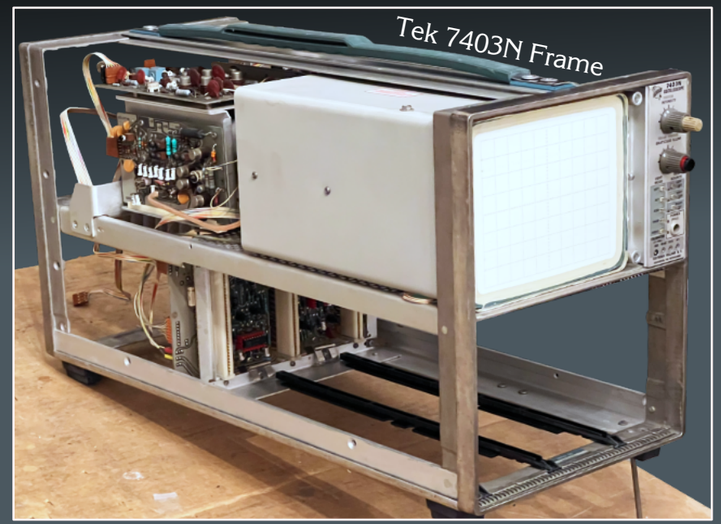
Shocking!

If you look at the inner structure of Tektronix 7400/7600 oscilloscopes in the photo below, and compare it to the picture on the previous page, you are probably shocked seeing how much Tek was inspired by the 180 design. That didn't surprise me before, because I thought the 180 Series came out after the 7000, but it was really more than three years in advance.

On the left, the 180A in front of the 1970 Tektronix 7403N, forerunner of the 7600 Series. The 180A body was definitely smaller (20 x 26 x 49 cm vs. 22 x 27.5 x 55)* and lighter (9.9 vs. 13.6 kg), but the 7304N had three plug-in bays instead of two and a much bigger CRT. Later in 1971, HP proposed also the large screen 182A, probably to match Tektronix' offer, but had never a readout system, while, in general, the 180s never reached the 7000-Series level neither their success.

***The reported sizes are not from data sheets, but measured by me and relative to the body, without taking in the account knobs and connectors.**





Cathode-Ray Tube

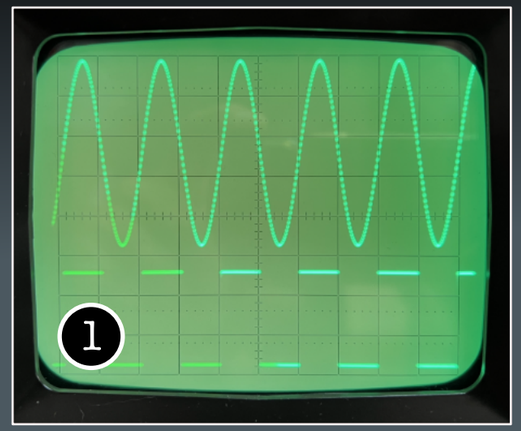
At the time, an 8 × 10 cm high-frequency CRT was considered definitely large, and that used in the 180A was also short. Leaving out knobs and connectors, it allowed the 180A to be only 49 centimeters deep, compared to 56 of the 7403/7603, 7 centimeters less.

They stated also that the picture area was from 30% to 100% greater than any other high-frequency scope. I can imagine that 30% was related to the 546's 6 x 10, while 100%, a little exaggerated, referred to the 453's 4.8 x 8 centimeters.

HP showed off the CRT sensitivity, with deflection plates requiring only a 3 V/cm drive. I am not familiar with this parameter, not always known by the user, but I believe that in this case it was more meaningful because no final vertical amplifier was present in the scope; the deflection plates were directly driven by the vertical amplifier plug-in.

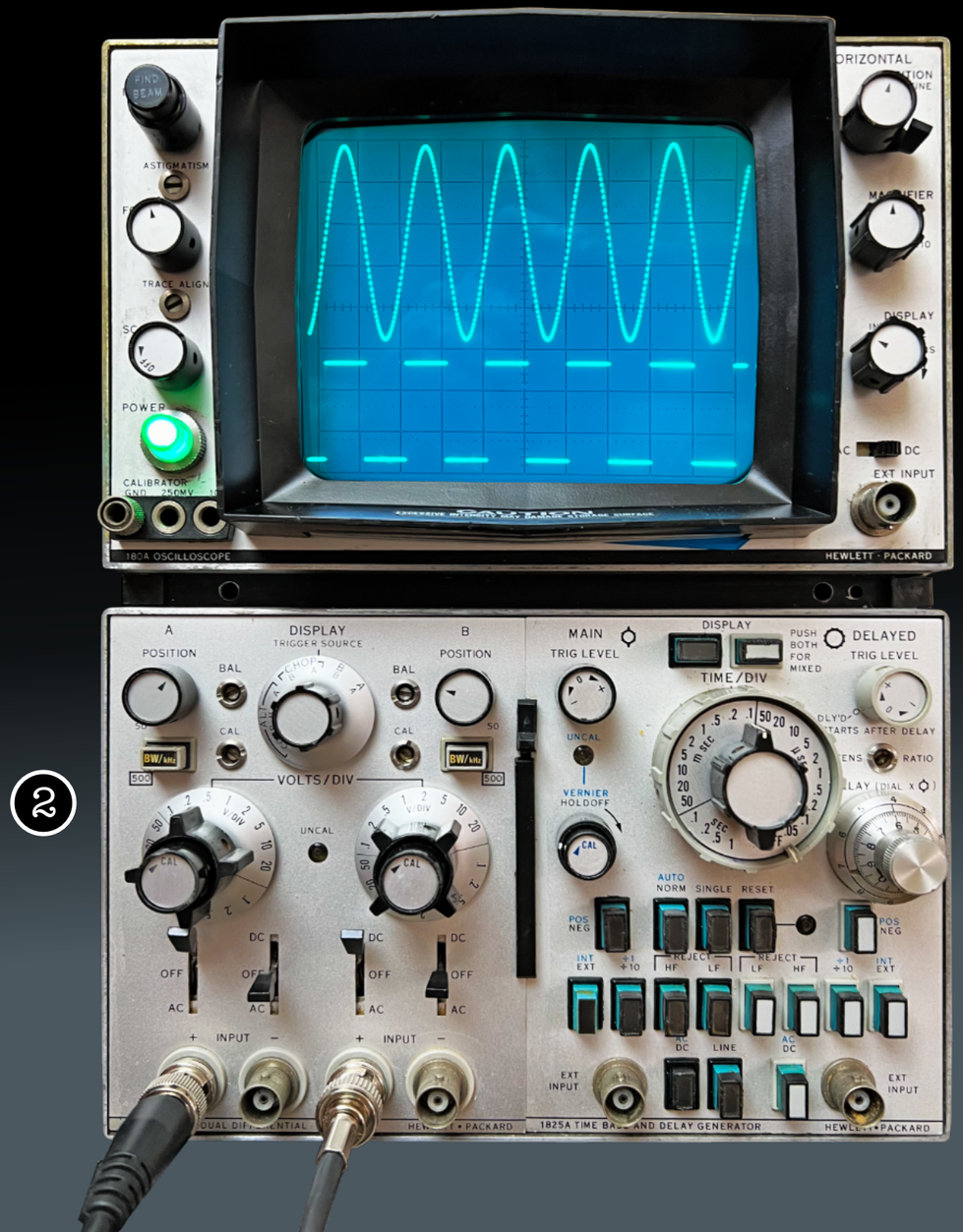
Aiming to produce bright, easy-to-see traces, even at 5 ns/cm sweeps, a 12 kV accelerating potential was used, 2 more than the 546, but 3 less than the future 7603,

The internal graticule calibrated in centimeters for eliminating parallax error was already common at the time, but they used a a lighting system that I never saw before; flood guns allowed variable background illumination for optimum contrast of graticule and trace, offering the unusual look you can see in photo 1 here on the right.



❶ The flood gun effect is to produce a uniform background lighting of the screen. Without the optical filter, it is more evident. Note the chopping effect of the dual-trace 1806A plug-in. The partial yellowish effect is due to the photo and it is not really present.

❷ 180A oscilloscope's front view. I added a home-made colored filter which greatly increases the contrast, because the original was lost. Still today, the CRT is bright, but not as much as my other 7000-Series scopes.



Plug-ins Delights

Plug-ins were not a novelty: Tektronix had introduced them many years before, and they were one of Beaverton's workhorses; too good an idea to be left out of a modern design.

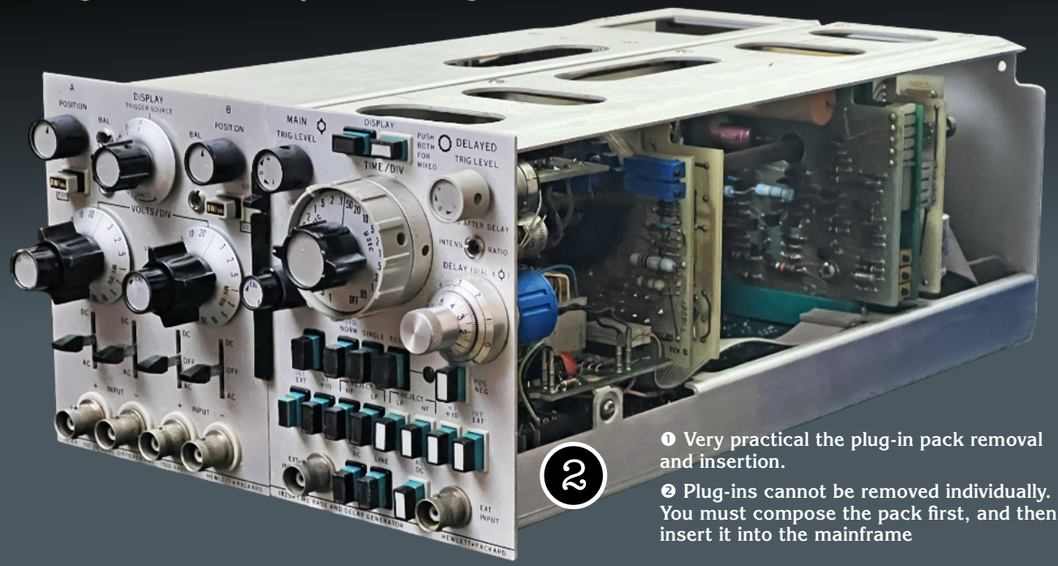
At launch, only three plug-ins were available for the 180 Series:

- 1801A dual channel vertical amplifier with DC to 50 MHz bandwidth and 5 mv/cm to 20 v/cm range;
- 1821A time base and delay generator (dual time base) from 1 s/cm to 10 ns/cm;
- 1820A time base from 2 s/cm to 5 ns/cm.

Obviously, the plug-in number was going to increase in the following years, and, in 1975, almost 30 of them were available.

Differently from Tektronix, plug-ins could be removed and inserted as a single block (photo below); in other words, to change just one of them, you had to remove them both; nevertheless, the operation is practical enough, as shown in the photo on the right.





❶ Very practical the plug-in pack removal and insertion.

❷ Plug-ins cannot be removed individually. You must compose the pack first, and then insert it into the mainframe

Setting the Tone

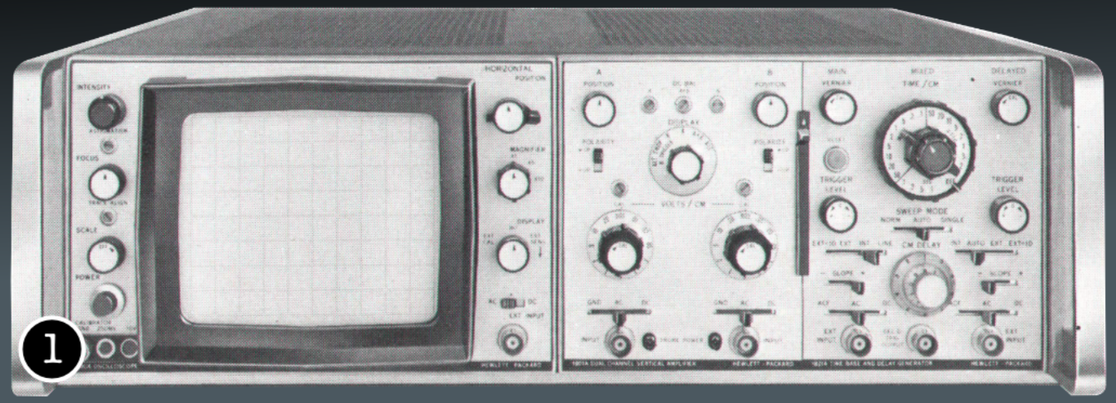
The 180 frame construction was defined aircraft-type. It was not only rugged and light, but also very smart, and was going to set the tone of oscilloscope design for the next two decades. No wonder that Tektronix took up its concepts in their 7000-Series project.

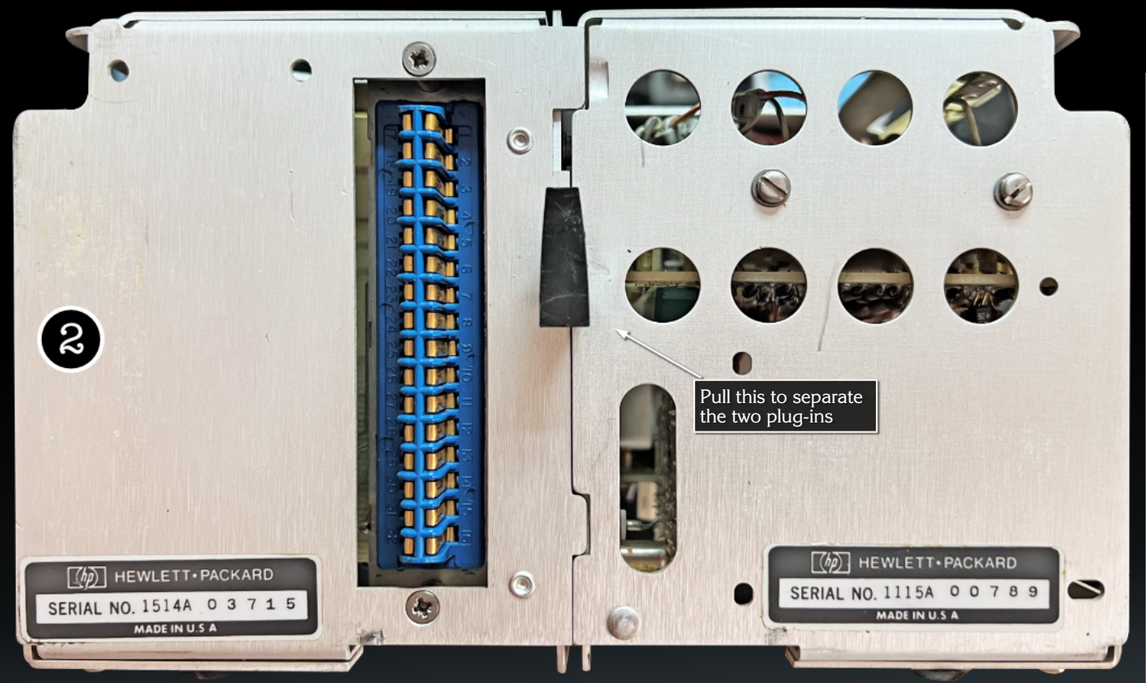
The construction was modular and composed by two units which could be mounted one above the other for the 180A cabinet version and side by side for rack mounting, to compose the 180AR (photo ❶). Also Tektronix. later, adopted this solution for the 5000 Series.

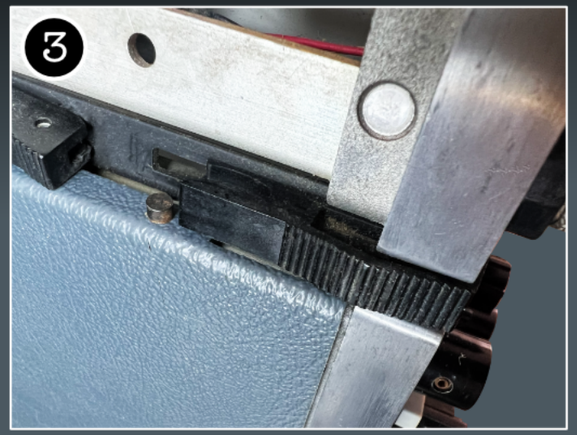
The plug-in assembly was very robust and used just one connector toward the mainframe (plus two contacts for the vertical amplifier output, see later). This connector (photo ❷) was of “almost” the same type used by Tektronix for the 500 Series (see next page), and was more reliable than the PCB direct insertion adopted in the 7000 Series, even if clearly more expensive also for the wiring.

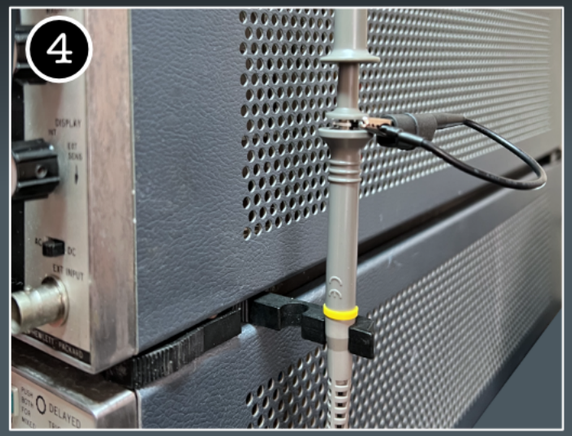
The oscilloscope covers had a very nice snap off locking system (photo ❸), which allowed to get to inner circuits without the need of a tool. It was later abandoned in favor of normal screws, perhaps for cost reasons. There was also a foldable probe holder as a courtesy complement (photo ❹).

❶ The 180AR, rack version of the 180A, built by using the same two modules. ❷ The rear side of the plug-in pack. Note the sturdy connector and the knob to set apart the two plug-ins ❸ The very practical snap-off locking system of the oscilloscope covers. ❹ The foldable probe holder, one on each side.









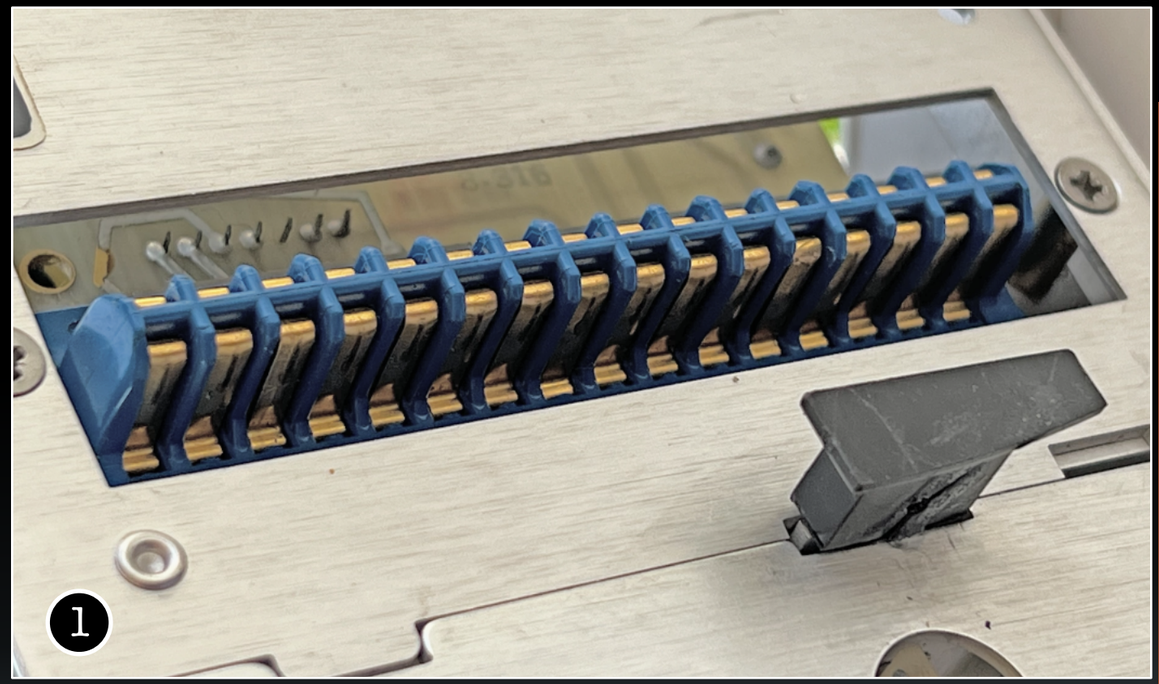
Connectors & Connectors

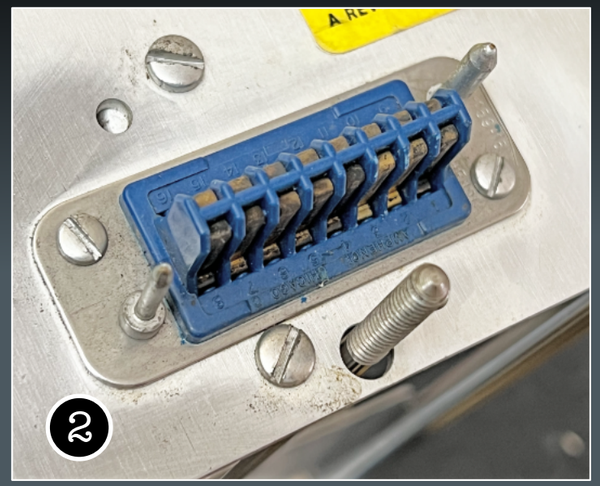
I met these connectors first when I started working on buses on-board equipment. They were used for old ticket cancelors. They were difficult to find and expensive, so, for the new electronic validators, rather complex devices, I decided to switch to an ISO automotive model (which, over the years, became difficult to find as well, and we had to produce it too). I always thought there was just one type, but our friend David from Group.IO warned me on this point, so, after a little search, I can be more precise, because both Tek and HP used the same 26-Series of Amphenol connectors, but:

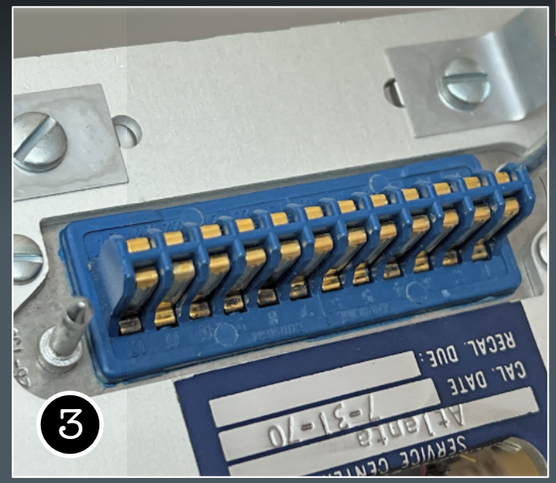
- Tektronix used in Series 530/540 the 26-159-016;
- Tektronix used in Series 560 the 26-159-024;
- HP used in 180 Series the 26-4100-32P.

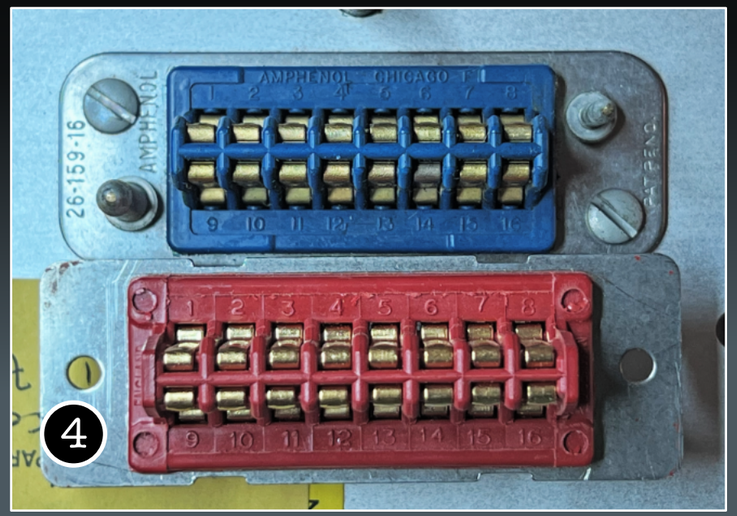
The Tek used the model with pin polarization, suitable *"…for blind mating situations…pins mate before contacts for perfect alignment"*, while HP used the barrier polarization "*…dielectric barrier prevents mismating..used in most rack-and-panel or module interconnections"*.

By the way, even if not specifically indicated on Amphenol data sheet, the two types have different pin pitch, being that by Tektronix more dense, as shown in the photos.







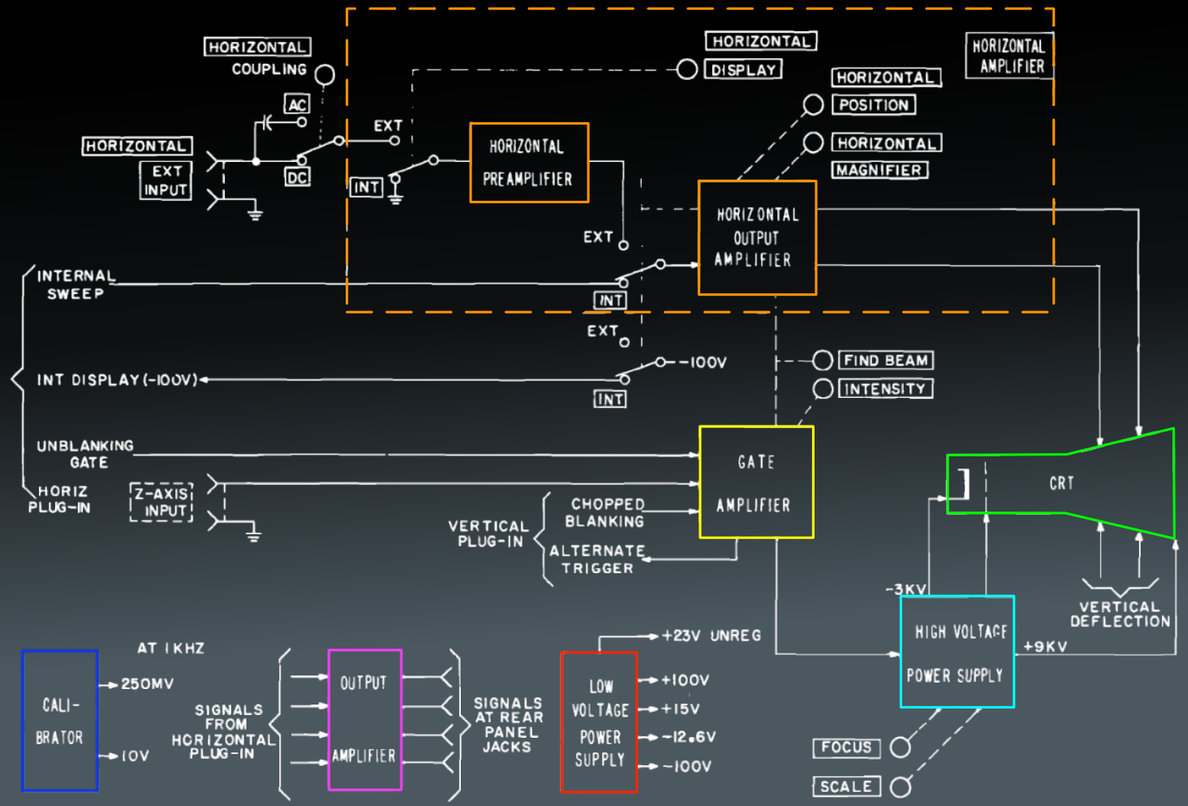


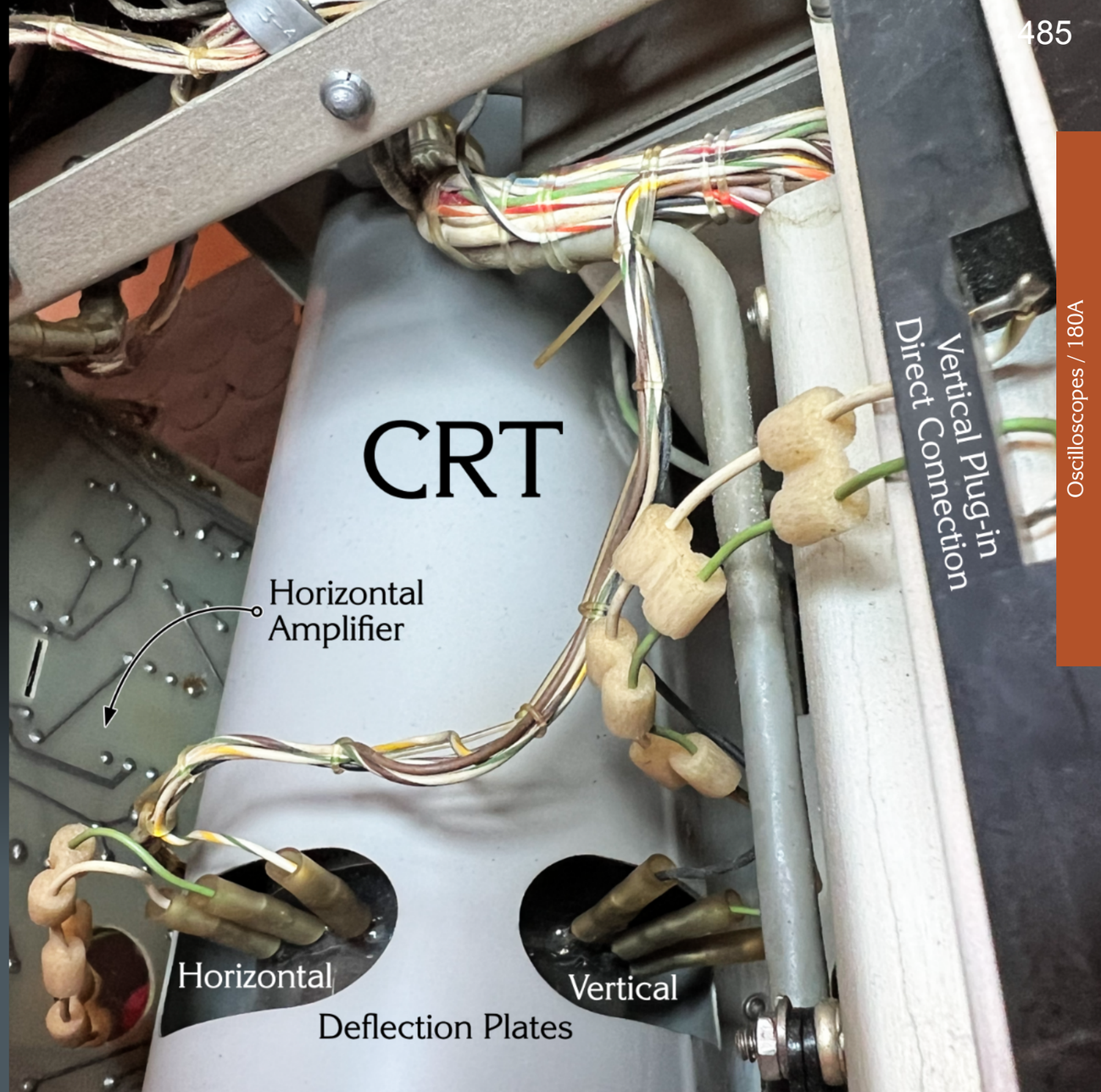
❶ The HP 180-Series connector.
❷ The Tektronix 530/540-Series connector.
❸ The Tektronix 560-Series connector.
❹ Comparison of the old cancelors' connector (similar in pitch to HP) with Tektronix. The difference in pitch is evident.

Circuitry

The 180A's circuit was rather conventional and reasonably simple; it is evident the wish to "delegate" most of the functions to plug-ins, keeping the mainframe relatively light. In particular, no vertical amplifier was provided, but just the access to vertical deflection plates.

Valuable the extended temperature range, from -28°C to +65°C and the declared resistance to shock and vibration, suitable for portable use. Very good the accessibility for repairs.





Electrical Performance

Triggering

- Capability to 90 MHz and above.

Horizontal Amplifier

- Sweep speed: up to 5 ns/cm;
- Sensitivity: 1 V/cm, x1; 0.2 V/cm, x5; 0.1 V/cm, x10; vernier provides continuous adjustment between ranges;
- Dynamic range ±5V;
- External input: bandwidth: DC coupled, DC to 5 MHz; AC coupled, 5 Hz to 5 MHz. Input RC: 1 MΩ shunted by approximately 30 pF.

Component Quality

- Premium components-capacitors, potentiometers and metal film resistors.

Power Supply

- Voltage: operates on 115 or 230 volts, 50-1000 Hz, 95 watts;
- Convection cooled (no fan).

Calibrator

- Waveform: approximately 1 kHz square wave, 3 μsec rise time;
- Voltage: 2 outputs, 250 mV and 10 Vp-p, ±1%.

Z-Axis

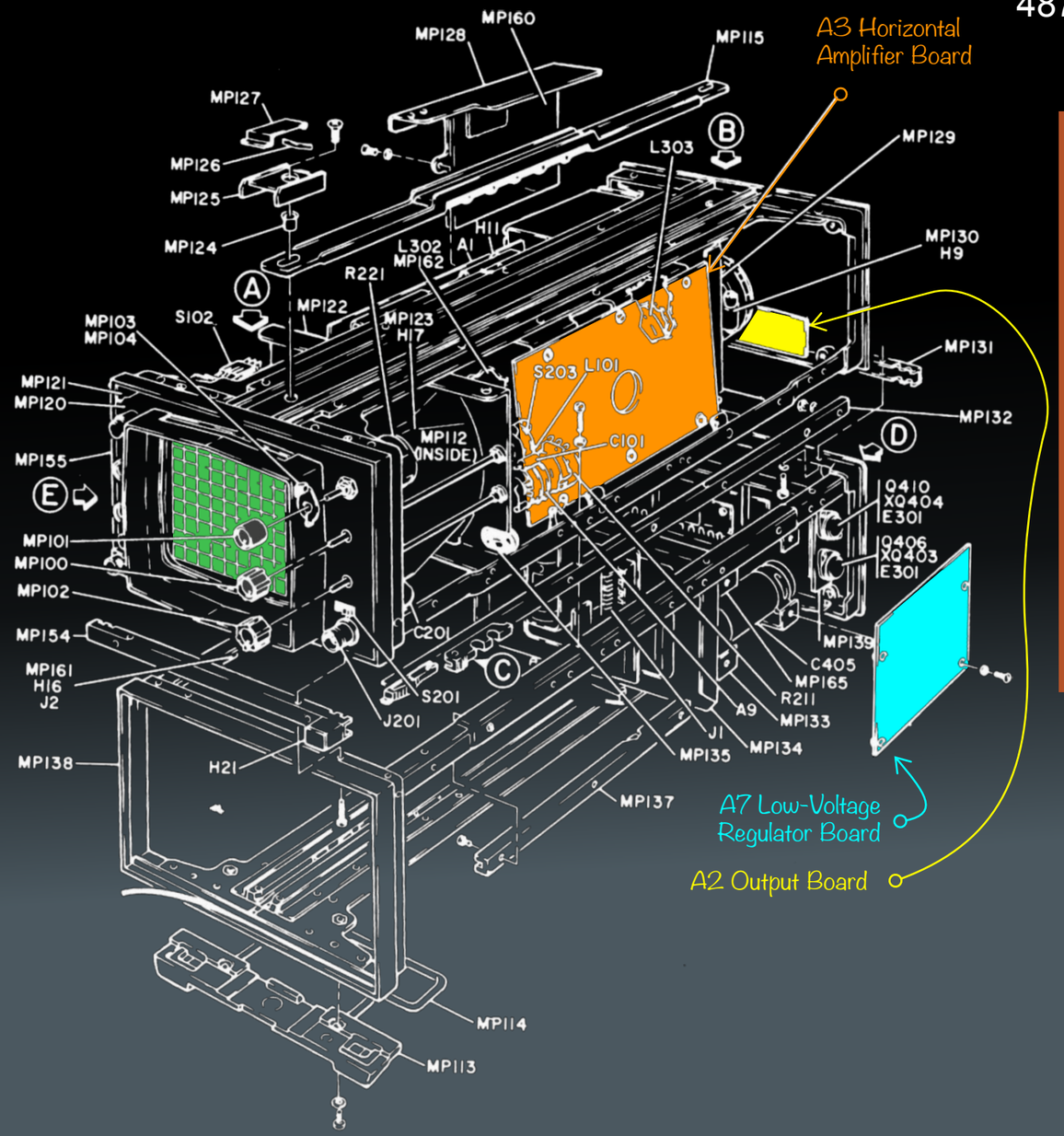
- Input: approx. +2 V, DC to 15 MHz, will blank trace of normal intensity. Input resistance: 5.1 kΩ.

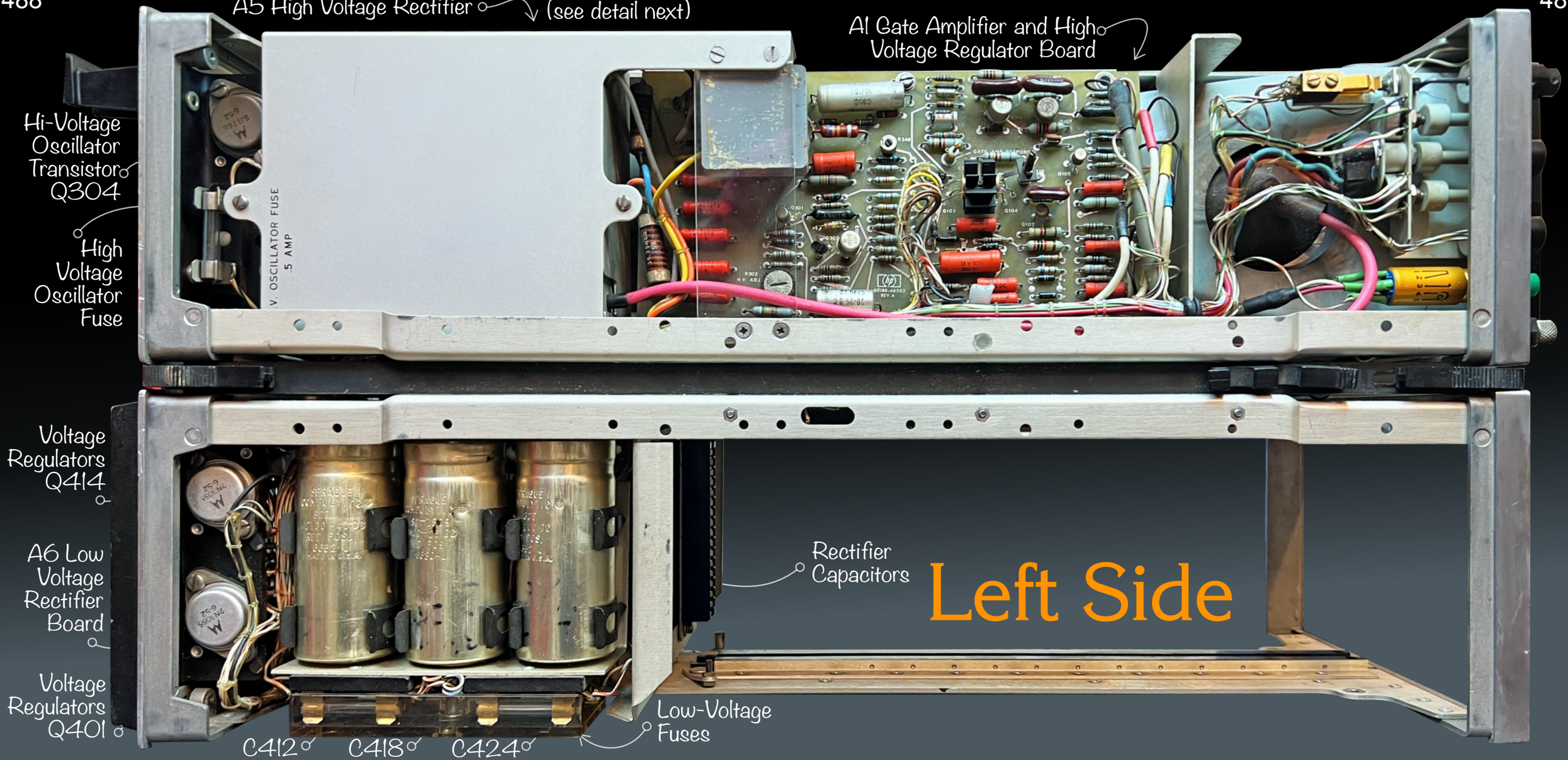
CRT

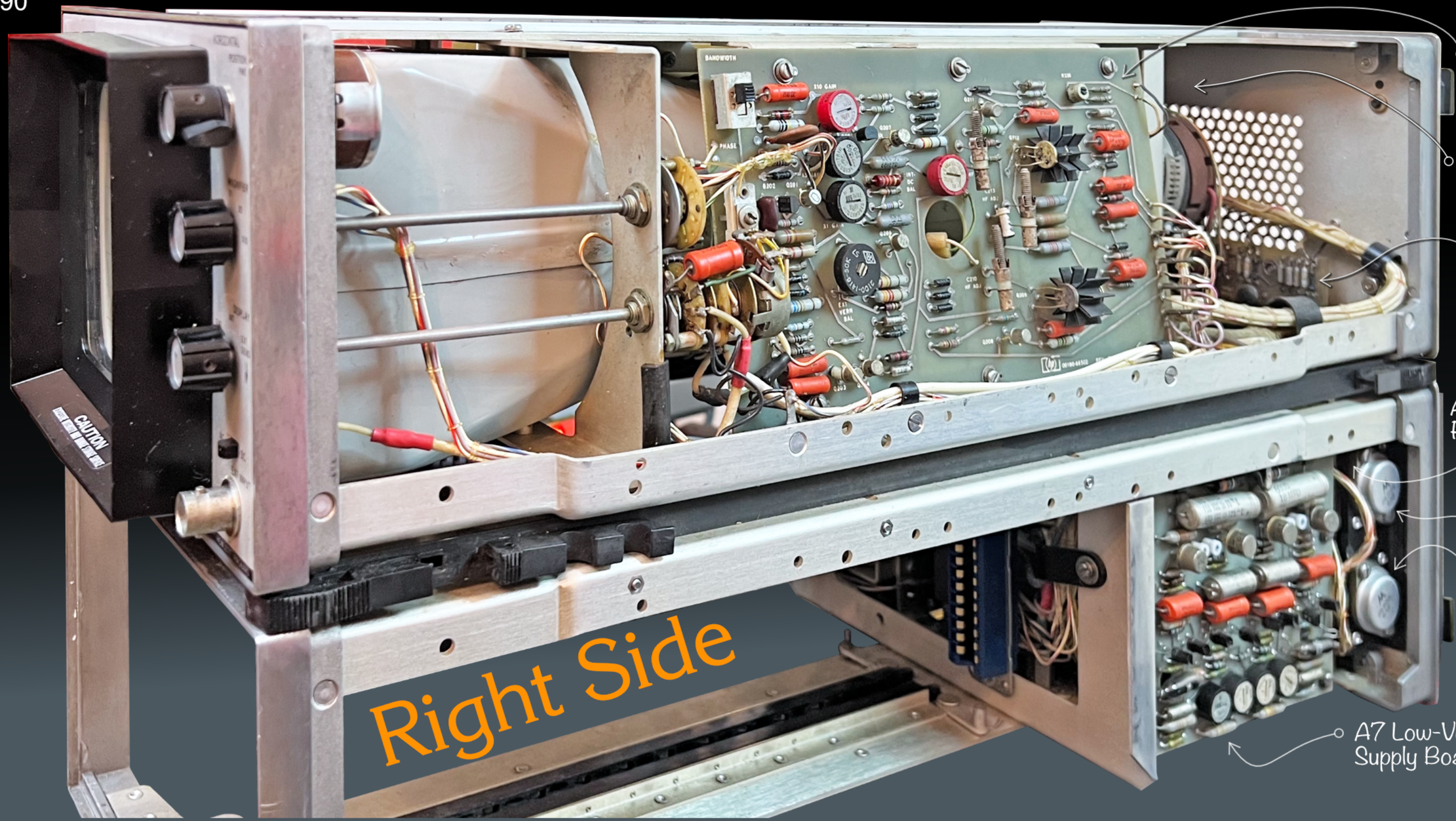
- Accelerating potential: 12 kV;
- Phosphor: aluminized P31 phosphor (P2, P7, and P11 available upon request);
- Writing rate: approximately 700 cm/sec (using HP 197A Camera with f1.9 lens and Polaroid® 3000 speed film), P31 phosphor;
- Graticule: 8 x 10 cm parallax-free internal graticule; CRT phosphor can be illuminated for viewing with hood or taking photographs.
- Adjustments: front panel recessed controls aligns trace with graticule; internal Y-align aligns Y-trace with X-trace.

Outputs

- Four emitter follower outputs for main and delayed gates, main and delayed sweeps. Maximum current available, ±3 ma. Outputs will drive impedances down to 1 kΩ without distortion.

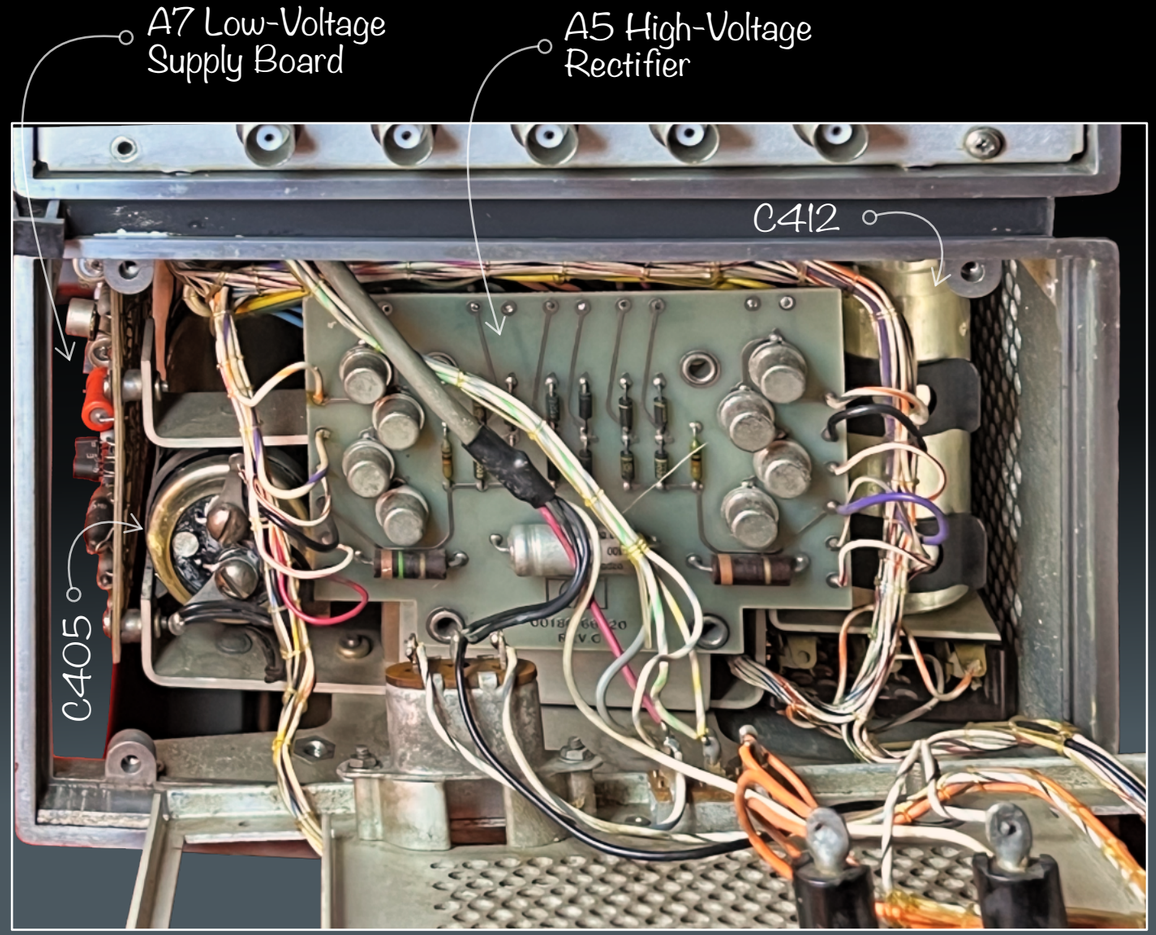


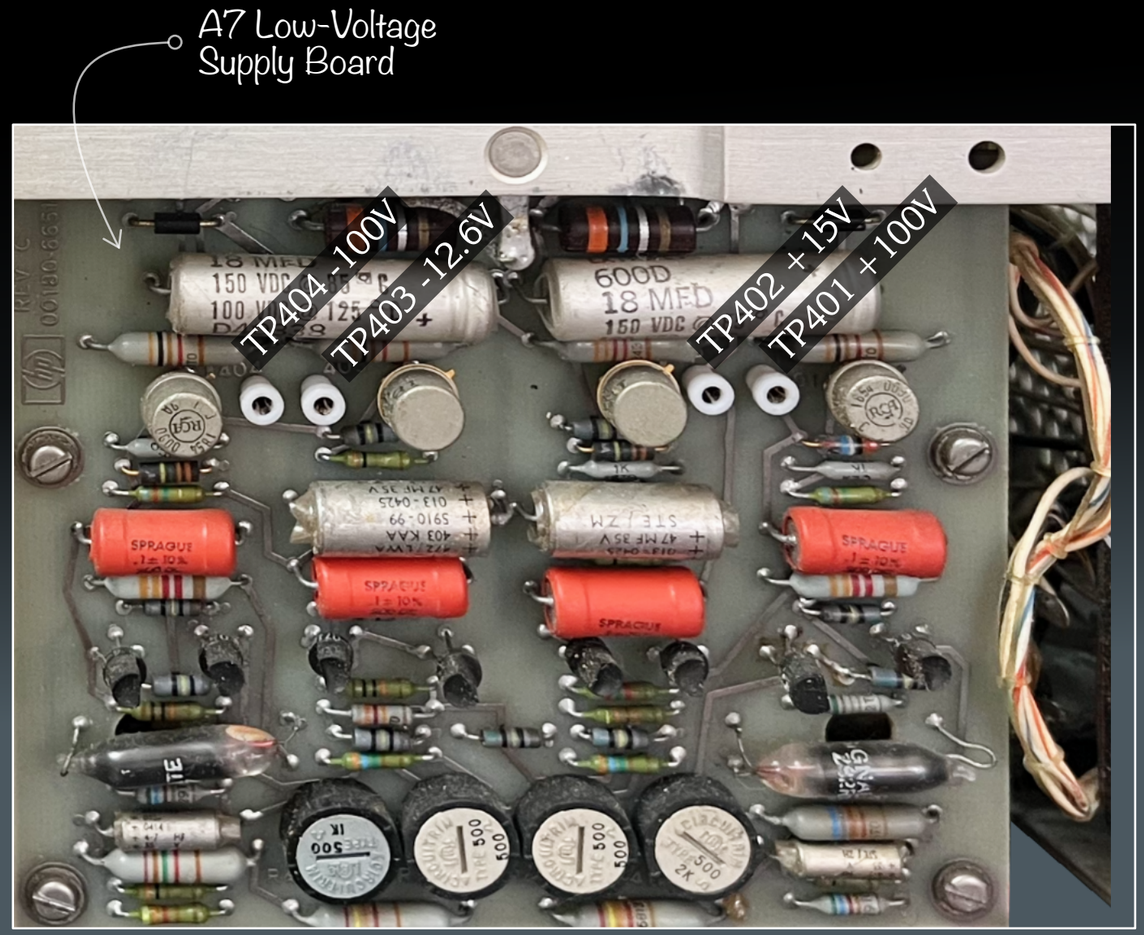

A5 High Voltage Rectifier
(see detail next)
A1 Gate Amplifier and High Voltage Regulator Board
Hi-Voltage Oscillator Transistor Q304
High Voltage Oscillator Fuse
V. OSCILLATOR FUSE
.5 AMP
Voltage Regulators Q414
A6 Low Voltage Rectifier Board
Voltage Regulators Q401
Rectifier Capacitors
Left Side
C412
C418
C424
Low-Voltage Fuses


A3 Horizontal Amplifier Board
A4 Hi-Voltage Oscillator Board
A2 Output Amplifier Board
A6 Low-Voltage Rectifier Board
Q410
Q406
Voltage Regulators
A7 Low-Voltage Supply Board
CAUTION
BANDWIDTH
PHASE

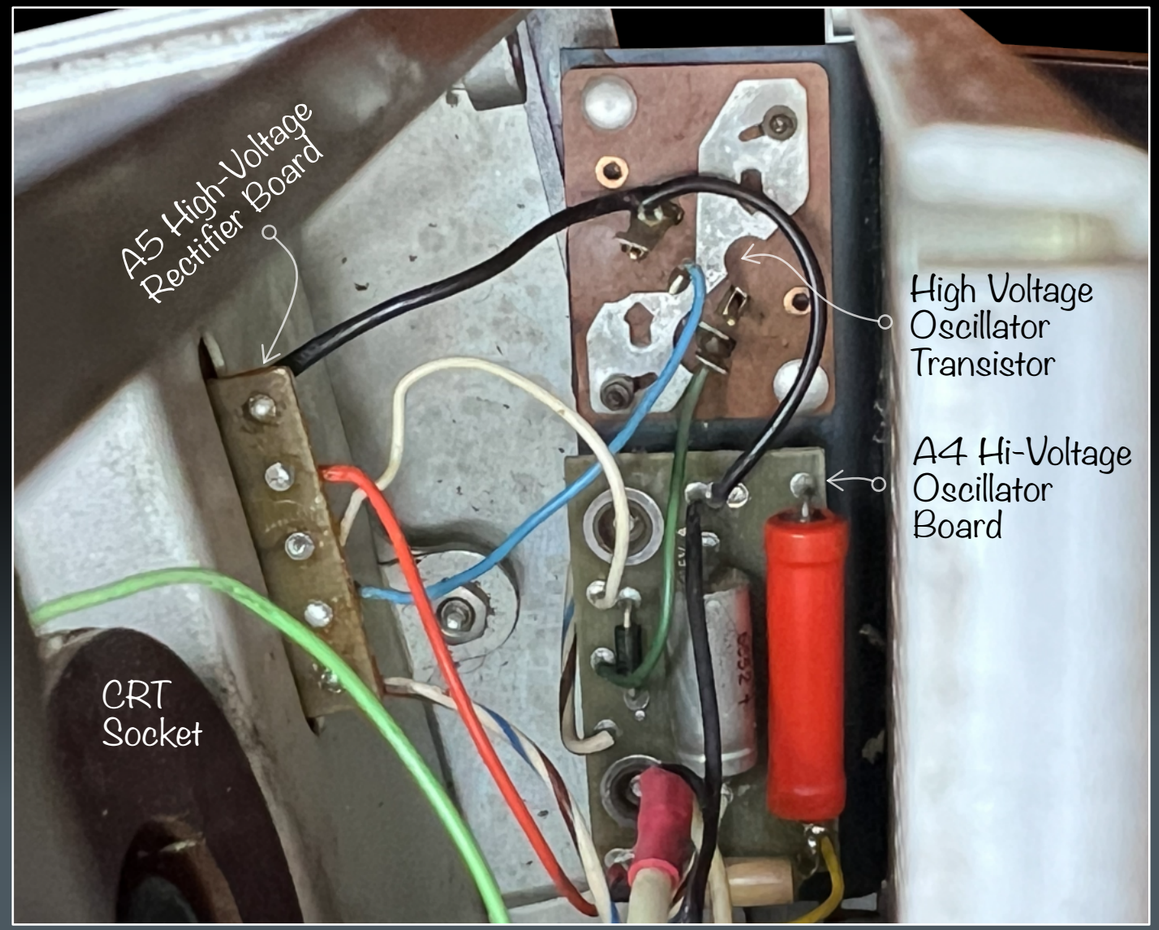
Right Side

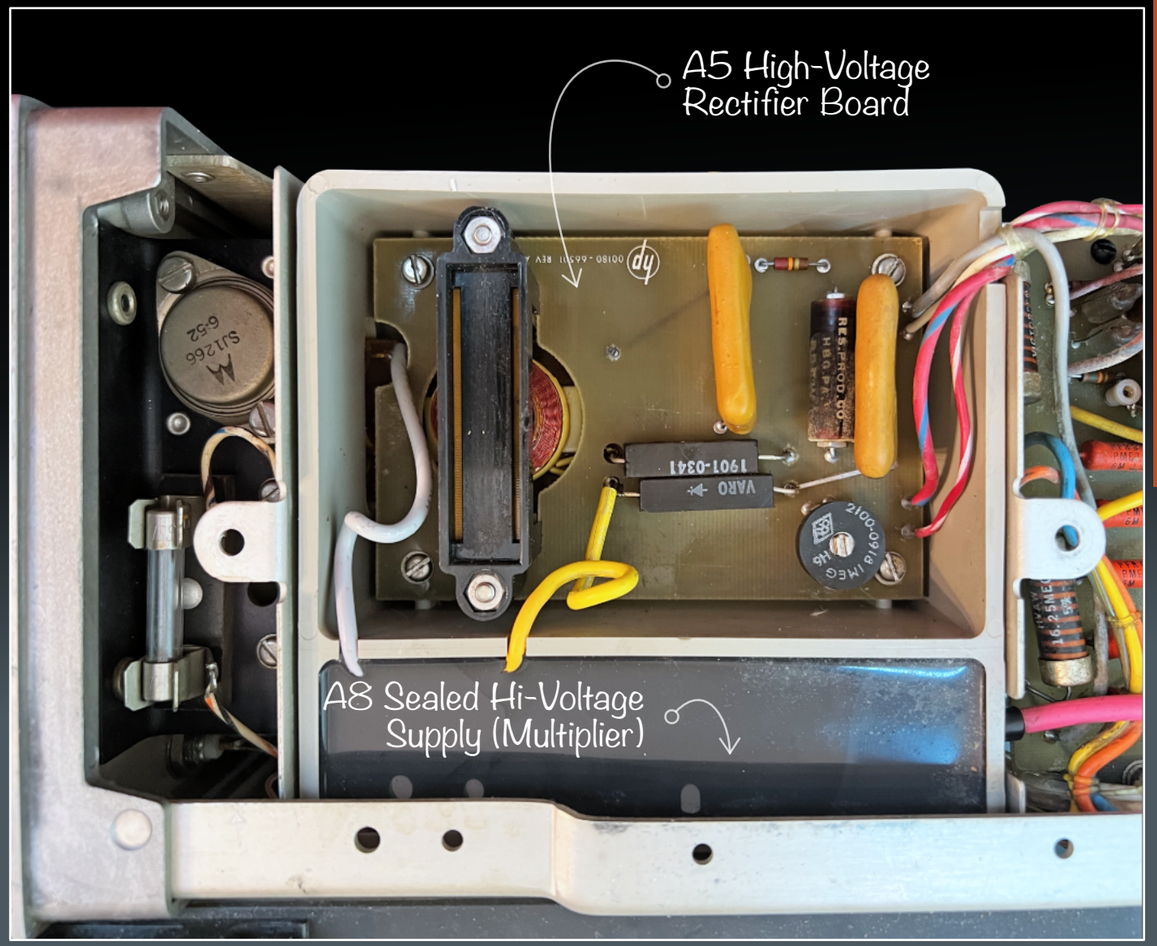
Low-Voltage Power Supply





High-Voltage Power Supply





180A Repairs

Ten Euros Each

As I told you, I bought four pieces (two mainframes and two plug-ins) for 40 euros, i.e. for €10/piece. I could not expect that they were nothing more than scraps. In reality, things were much better, and they needed only …a little love, to return into operation.

Documentation

You can find the 180A's manual online, but they are of poor quality, so I ordered it from Artek. Ten times better. But the manual for the 1806A plug-in was not to be found, neither for free, nor for a fee.

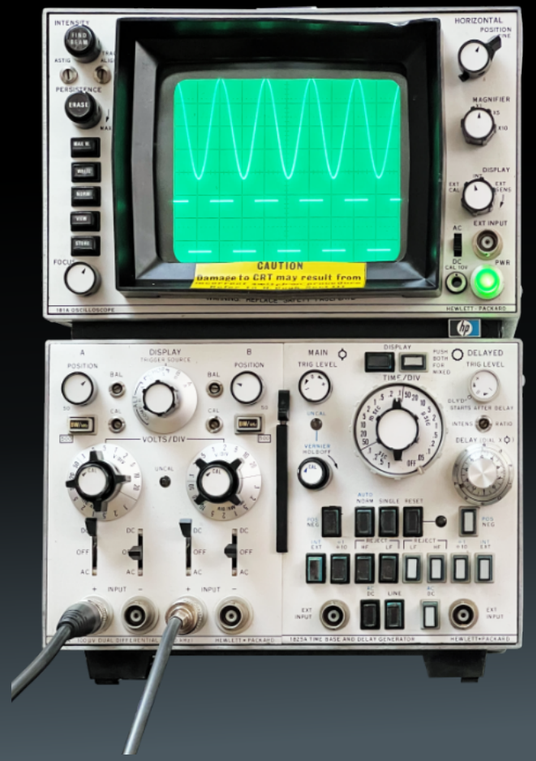
Often, I am torn and don't know if replace the filter capacitors. On the one hand, I would like to keep the original ones, but on the other I fear that they could short and damage the power transformer. In this case, a low voltage fuse (-100 V) was blown, and that made me think to the worst.

Few Things to be Fixed

I decided to check the big cans and then opt for the proper solution. I dismounted and checked C412, C410 and C424 in all the ways I could imagine: with a modern capacimeter, with the ZM-11/U, with the ZM-3/U and keeping them under voltage and measuring the current. Considered that they had no leakage signs, I concluded that I could keep them in place. But the big C405 had instead a visible bulge (photo), and so I cut it and inserted in the can a modern 470 μF 200V. With just this, the old 180A returned to life with my joy. All the four voltages were good and very precise. The HV was a little low, but I decided to leave it as it was for now.







Section:

Oscilloscopes

Subsection:

181A Oscilloscope

One of the first CRT storage oscilloscopes of the new transistor age. Simple and powerful, is still today a nice instrument.



1966

181A Storage Oscilloscope

Variable Persistence

The May 1968 issue of HP Journal let us to understand that the storage scopes of that time were not automatically with the so-said Variable Persistence, and that the ability to vary the length of time that the trace afterglow remained on the screen opened the way to easier study of many kinds of waveforms.

Slow-moving Traces

Slow-moving traces could be displayed in their entirety and slowly erased just as the next one comes along; waveforms of constantly changing signals could be superimposed on the screen for comparison; and a group of one-shot signals might be held on the screen for study without resorting to photography.

With Variable Persistence, a complete sweep could be displayed on the screen without overlap from one sweep to the next. This was accomplished by adjusting the persistence so that the old trace faded from view just as the new trace was being written. There was no annoying flicker and no need for continuous adjustment of the oscilloscope controls. This allowed observation of slow-moving, constantly changing waveforms such as those produced by biomedical phenomena, vibration, or dynamic strain.

There were many other situations in which the Variable Persistence oscilloscope could provide the best display of a signal difficult to observe. In time-domain reflectometry, spectrum analysis, or swept-frequency measurements, maximum resolution could be attained with low display rate. By adjusting the variable persistence and intensity controls on the scope, the information on the CRT could be made much easier for the operator to interpret.

High Frequency

Variable Persistence was also useful for high frequency work. To view repetitive fast risetime pulses with low-repetition-rate, a viewing hood was often required to see the dim waveform on a normal oscilloscope. With variable persistence, the trace could be allowed to “integrate up” and a bright display could be obtained.

Three in one

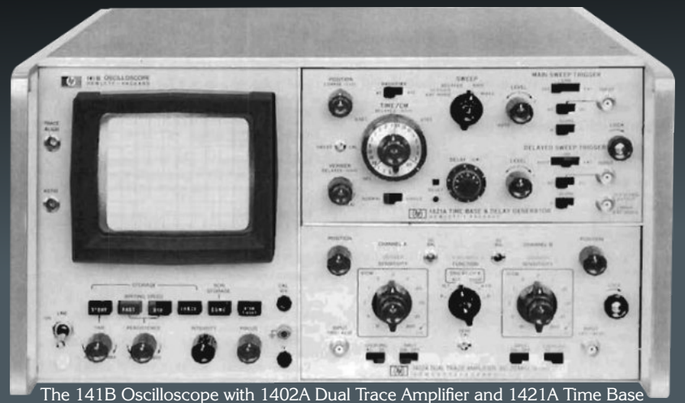
The Variable Persistence oscilloscope was promoted as being actually three scopes in one: a conventional oscilloscope, a variable persistence oscilloscope and a storage oscilloscope.

As a storage scope, the instrument could be used to observe single-shot events, to compare events which occur at different times, or to preserve events for observation at a later time.

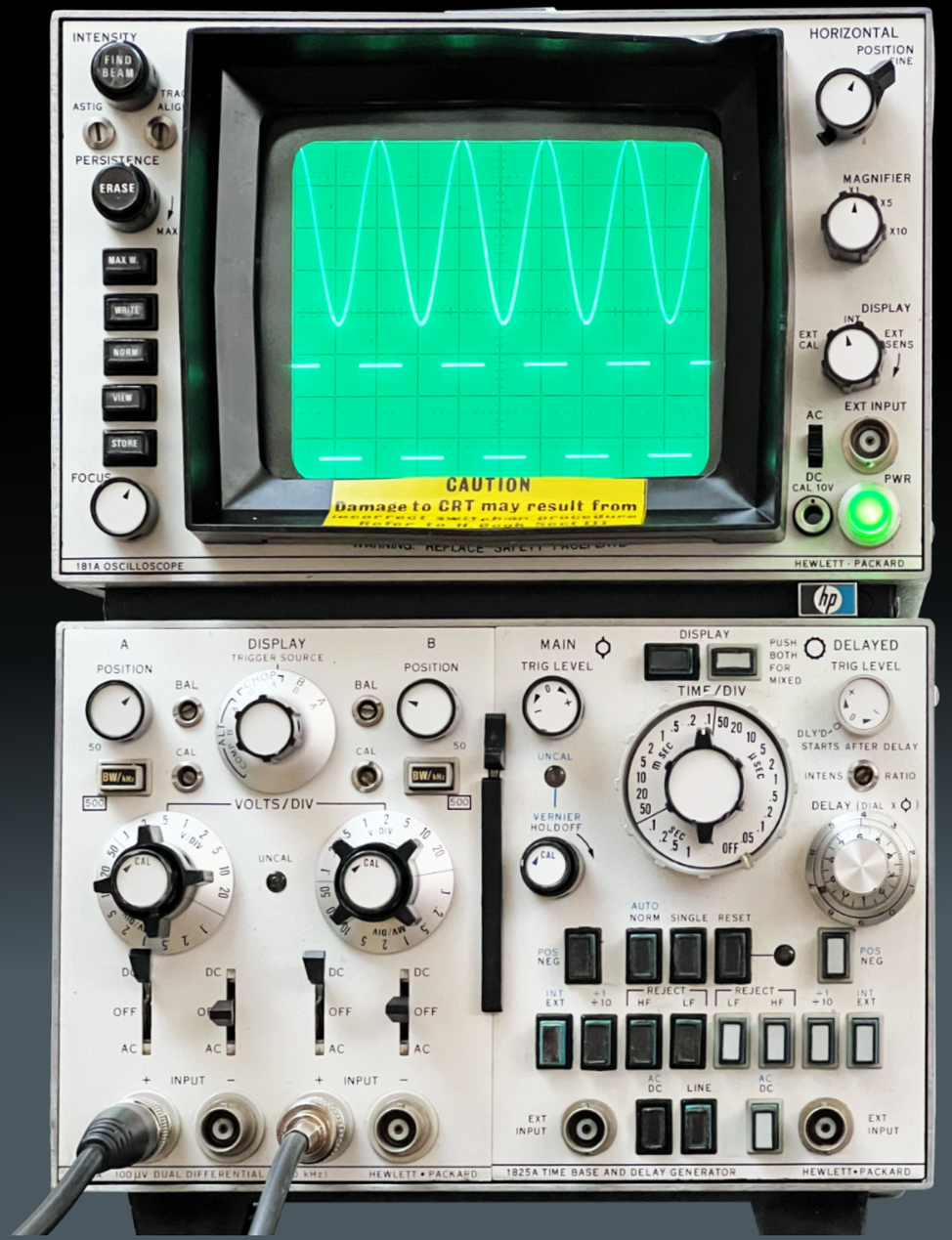
Hey, but I Know You!

The HP Journal states that Variable Persistence had been introduced by HP with the Model 141A appeared in 1966/67 catalog. The 181A was so a high-frequency oscilloscope, with the portability and flexibility of the all solid-state HP Model 180A, but with Variable Persistence.

Looking at the picture of the 141B, I said to myself *Hey, but I know you!*



The 141B Oscilloscope with 1402A Dual Trace Amplifier and 1421A Time Base and Delay Generator. It was almost like the 141A but with a rectangular CRT.



141T oscilloscope with 140-Series 8553B and 8552B Spectrum Analyzer plug-ins

Old Acquaintances of Ours

Effectively, I already met the Model 141T, and we talk about it in the section dedicated to Spectrum Analyzers (photo on the left). The Model 141T was designed to be an oscilloscope and to be used with 1400-Series plug-ins. It became a Spectrum Analyzer with the 8550-Series plug-ins. It has Variable Persistence and, by looking at it, I would say that the 141T was strictly derived from the 181A, more than from the 140. The 141T mainframe described in this book is a late one, with the oscilloscope beam finder switch & calibrator removed, intended for the spectrum analyzer plug-ins.

But it's not enough. I also forgot I talked about the 180A oscilloscope, repairing and describing my friend Francesco's 8557A Spectrum Analyzer (photo below). In reality, the 8557A is just a 180-Series plug-in, and the machine I worked on was composed by it and by the 853A display, a digital-storage version of the 181A dedicated to this kind of application.



853A display with 180-Series 8557A Spectrum Analyzer plug-in

These wonderful Spectrum Analyzers are described in this book in the relative section.

Better Dim than Burnt



My friend David from Group.IO, whom we have already mentioned, gave me a window into the CRT preservation problem pointing out a post by Radio Wrangler on www.vintage-radio.net (https://www.vintage-radio.net/forum/showthread.php?t=212114):

"The HP storage tubes were not protected to the extent that Tektronix protected theirs from mesh burns etc.", he wrote to me, *"This allowed the HP tubes to write faster (important for a scope, but not for a spectrum analyzer) The downside is that the operator had to really understand what was going on or else the CRT took damage. The problem was in it having a button for conventional non-storage use. You'd think you could just push this* [as I did] *and then drive it like an ordinary non-storage display. You'd be wrong. The fault was in not explaining in direct, simple terms. Marketeers didn't want to admit there could be problems with a product so they didn't tell you and so you damaged the thing.*

Never ever try to use a storage display as a normal non-storage one. Have it in storage mode with the persistence control turned to minimum. Advance the brightness control until it paints a trace. As you increase the brightness control the trace will start to bloom. Now back off the brightness to where you can see the bloom dissipate, leaving a single line trace. This is the max brightness you should use. With so much brightness that blooming happens, it is an indication that the electron beam current is high enough to slowly cut through the storage and electron lens meshes inside the tube. If you now select CONVentional mode, you get a dark background like a non-storage scope, but the trace is likely too dim for easy viewing. If you turn the brightness up, you can have a brighter trace, but electron-beam cutting has started and you don't get to see the warning bloom. You are damaging the CRT and nothing tells you. If you must use CONV, use normal speed storage mode to set the brightness first and be sure not to increase it. Redo if you change timebase speed."

All this is true for both the 141T and the 181A. If you, like me, are so lucky to have a good CRT, don't take chances. It is much better to use it in the shadow than taking chances about this old and probably today impossible to find CRTs (BTW: so, David let me to understand the cryptic warning messages reported below the CRT screens and above the housing of the 181A).

CRT Design

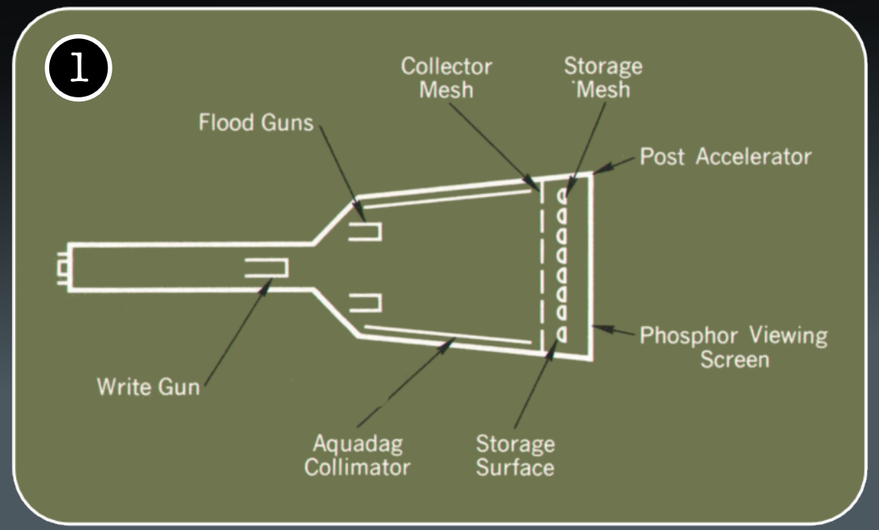
Coming back to the 181A description, I read that several important features had been incorporated into the design of the CRT for the 181A and that the rectangular 8 by 10 division CRT was the first rectangular, variable-persistence CRT to be manufactured in large quantities. Rectangular was not only more attractive but required less panel space than a round CRT.

181A's storage information is contained in a storage mesh located behind the phosphor. This allows a post-accelerator to be used so that bright displays are obtained in both conventional and variable persistence modes (the 181A CRT is slightly smaller than the 180A's: 9.5 mm/div instead on 10).

The use of the rugged P31 phosphor added to the viewing brightness, since its light output spectrum closely matches the spectral response of the human eye. These CRT's had a minimum specification of 100 foot-lamberts brightness in the variable persistence mode of operation, which is comparable to the brightness of a standard oscilloscope.

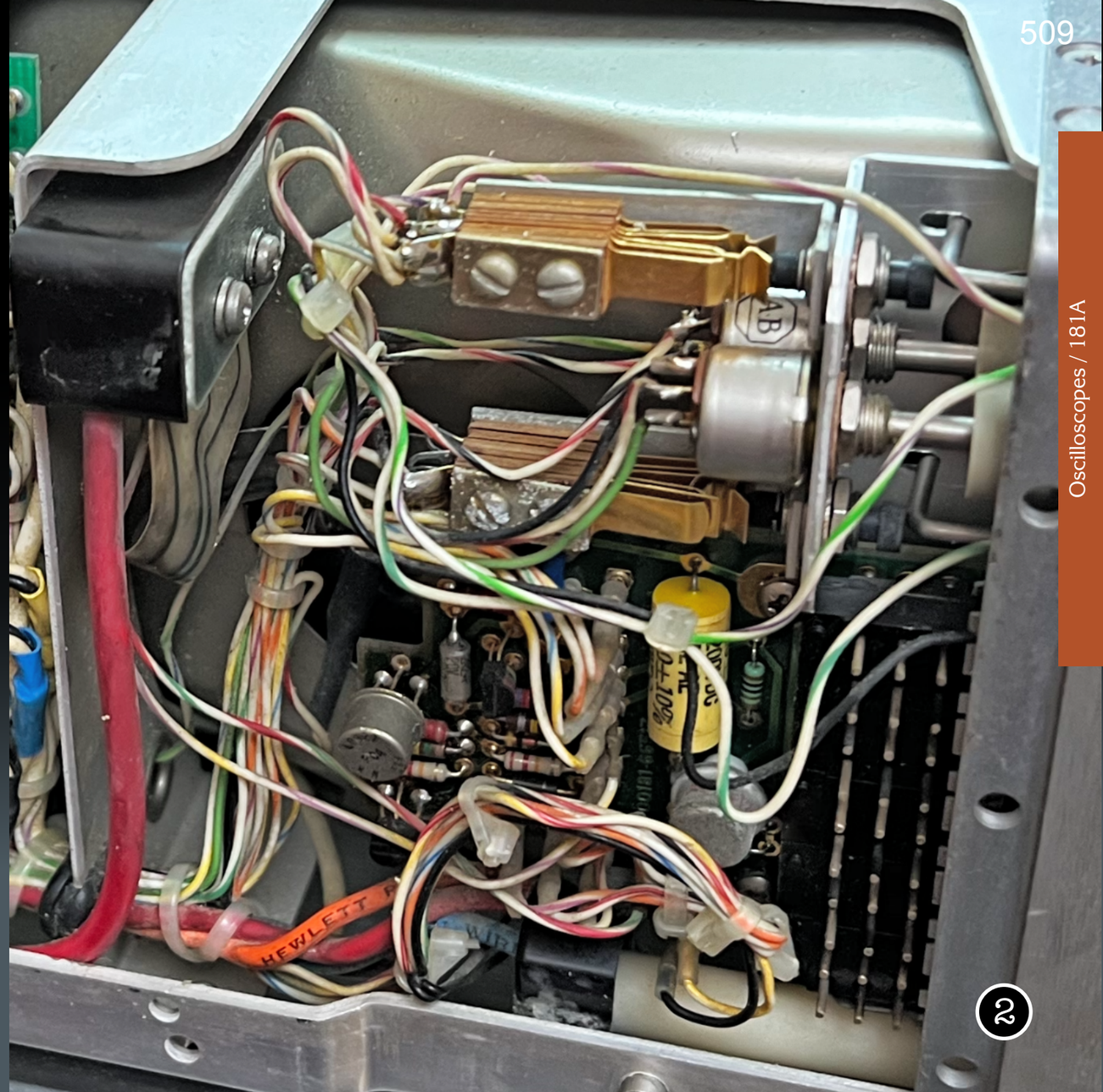
CRT Construction

The CRT consisted of a conventional electron gun with deflection plates (write gun), an aluminized phosphor viewing screen, a pair of flood guns operated in parallel, flood beam shaping and accelerating grids, a flood collimator, a collector mesh and a storage mesh, all shown in picture ❶.



We talked a lot about CRT-storage technologies in the book about Tektronix 7000 Series [2], and we refer the reader to it.

❶ A scheme of the CRT's basic structure.
❷ The rear of the button board added in the 181A to control the storage functions.



How Fast Is It?

How does the 181A relates to Tektronix CRT-storage scopes we already know?

HP declared its writing speed as 20 cm/ms in WRITE mode (0.02 cm/μs) and greater than 5 cm/μs in MAX WRITE. The Tektronix 7613 offered 5 div/μs, but a division was 0.9 cm, so really 4.5 cm/μs. The 7613 was introduced in 1972, and so six years after the 181A. A fairer comparison could be with the 564B (1962), described in the *Tektronix Epic Oscilloscopes Supplement* book [1], which was at 25 cm/ms (but on six vertical divisions only).

So the 1966 181A was much better than the 1962 Tek 564 (or 549), a little better than the 1972 7613, but light-years behind a 1972 7623 or a 7633.

We can conclude saying that in the last years of the sixties, the 181A was a good buy as a CRT-storage scope, probably among the best available on the market at that moment. Technology evolution later relegated it among the slowest CRT-storage oscilloscopes.

The Optical Mesh

The term mesh reminded me another mesh, which was supplied with the 181A to increase the optical contrast of the CRT, in place of the colored optical filters I was used to.

I had never seen one of these meshes before and I am not sure what it was intended for, but its effect is not bad and eliminates almost completely any reflection, as shown in all the 181A photos here. The unretouched picture on the left shows the absence of reflections and, enlarged on the background, allows to see the mesh's plot.

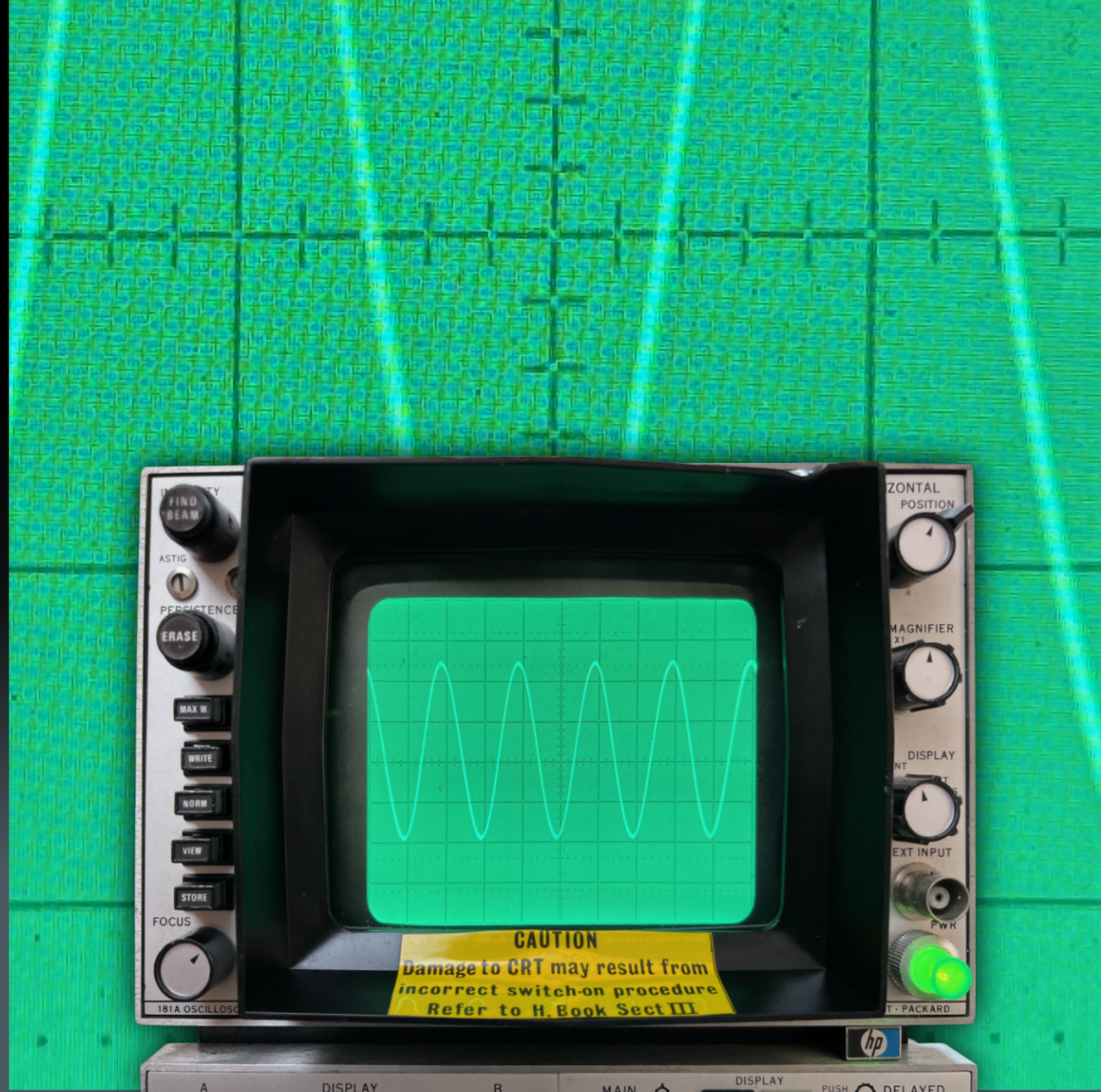


More on CRT Storage Scopes

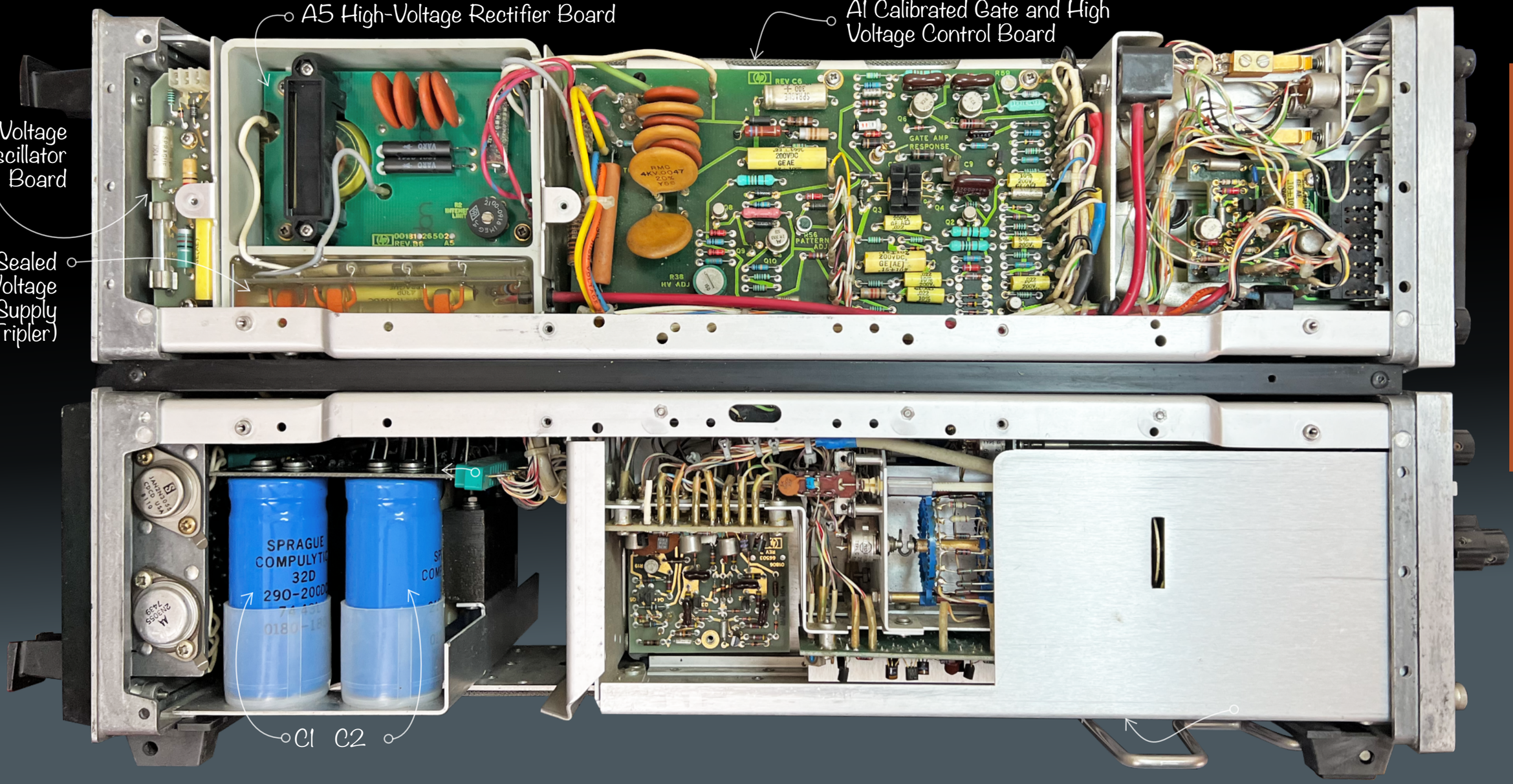
My free e-book *Tektronix – The 7000 Series* [2] is dedicated to 7000-Series oscilloscopes, their technologies, and their restoration, but, above all, to those who created them, and must be considered as an in-depth analysis, aiming to complement my *Tektronix Epic Oscilloscopes* book [1], where the 7000 Series is only briefly depicted.

An in-depth analysis is dedicated to CRT-storage technology and models.

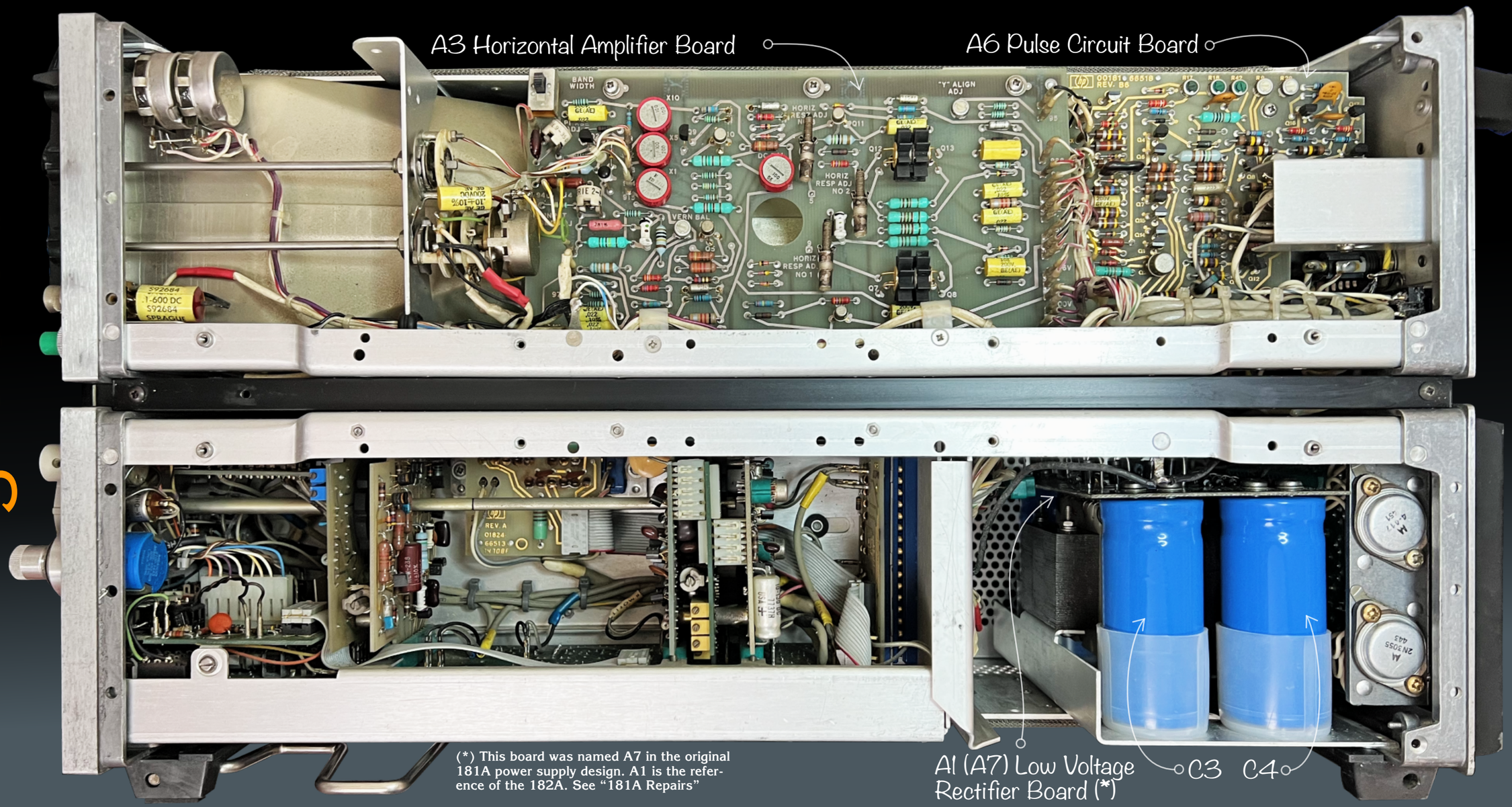
You can download it from my web page http://www.k100.biz, together with many other free books.



Left Side


A5 High-Voltage Rectifier Board
A1 Calibrated Gate and High Voltage Control Board
A4 Hi-Voltage Oscillator Board
A9 Sealed Hi-Voltage Supply (Tripler)
C1
C2

Right Side



(*) This board was named A7 in the original 181A power supply design. A1 is the reference of the 182A. See “181A Repairs”



Not Only the Colors

My two 180-Series scopes show unexpected differences, probably due to the project evolution. The 180A is older, the 181A is more recent, but, without any ICs, I have no elements for locating them in the time (the 1825A plug-in has ICs and they are from 1977).

The most evident modification is the body color, passed from a certain blue I already found on my 410C voltmeters, to the typical light brown/beige which characterized much HP equipment for many years.

But other details show the change. For example the housing covers, equipped with a quick snap off system in the 180A, left the place to eight conventional screws in the 181A.

Both of them had the handle broken, probably more prone to the time's action. In the 181A, perhaps it was the origin of the crash described in the next "Repair" chapter (Tektronix used a metal core in the handle to avoid this problem).

Also described in the "Repair" chapter, the new 181A power supply section, which became identical to the 182A, the "large screen" version of the 180A, but which was not shown in the manuals I could find. The new one is better engineered and easier to be repaired.

In my experience, HP used to update their products during the production, without any variation in the product denomination, differently from Tektronix. Manuals have then a large change log (but you must to find the last one…).

181A Repairs

Lost in the Jungle without a Map

I decided to risk, and tried to power the 181A up with no preliminary checks, but nothing happened, so I was forced to investigate. As mentioned, I discovered that my 181A power supply is different from the free manuals you can obtain from Internet. So I ordered the service manual from Artek; again, its quality is incomparably better, but it neither covered my model.

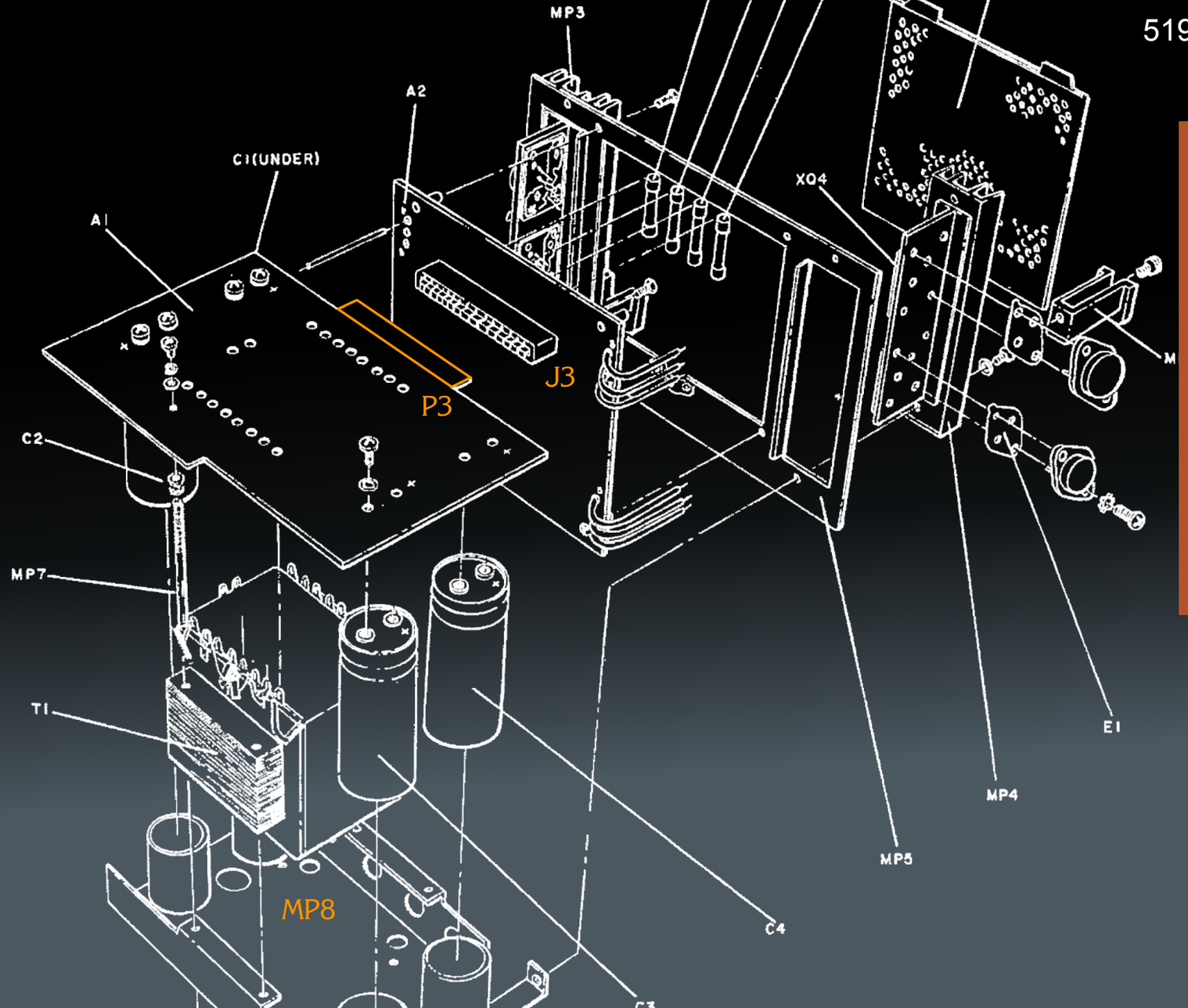
A Better Power Supply

I thought: maybe that mine is newer… but perhaps it is similar to some more recent model. So I tried with the 182A (the "large screen" 180A) and… BINGO, it was! Evidently, at a certain point they decided to adopt a new circuit and updated all the models. The difference is that previous wire connections have been replaced by direct insertion, gold plated edge connectors, as shown in the exploded view on the right, taken from 182A's manual. Note that the A2 Low-Voltage Regulator Board has been moved from the right side, where it was in the 180A, to the rear panel, where it can be accessed through a small door. Much more practical.

To Battle

Made stronger by the manual, I was ready to go into battle. I disassembled the 181A and I discovered that P3 connector was not inserted, as it should, in the A2 board. I tried to insert it, but it wasn't possible. The two connectors were on different levels and couldn't match each other. In short: the scope received a shock and the transformer support was imperceptibly deformed and lowered (see photos on next pages).

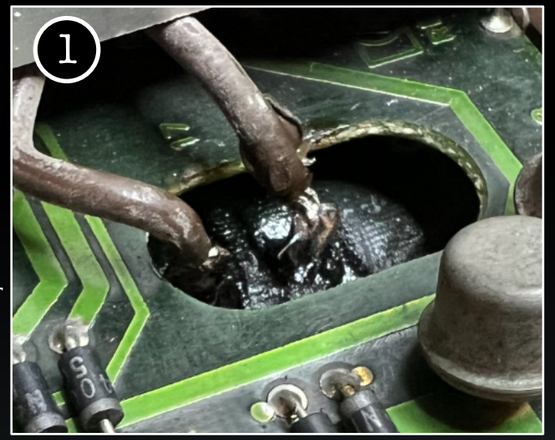
I disassembled the MP8 aluminum support and in some way straightened it, reporting P3 to the right level.



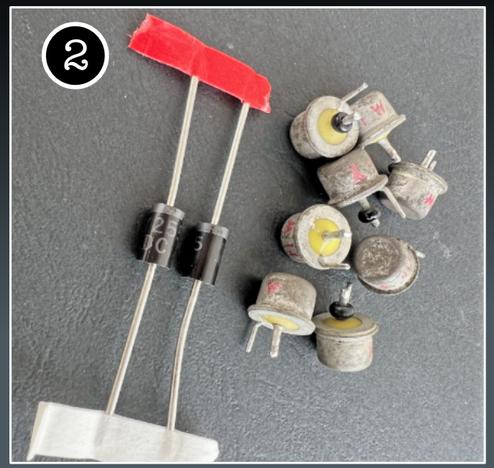
A Battle is not the War

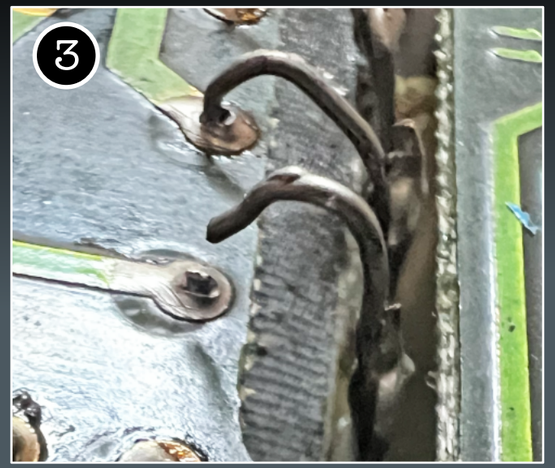
I would say that I fixed the 181A problems, but it was not so, and, to be honest, I had to disassemble and reassemble the power supply an inglorious number of times. The problem were the following:

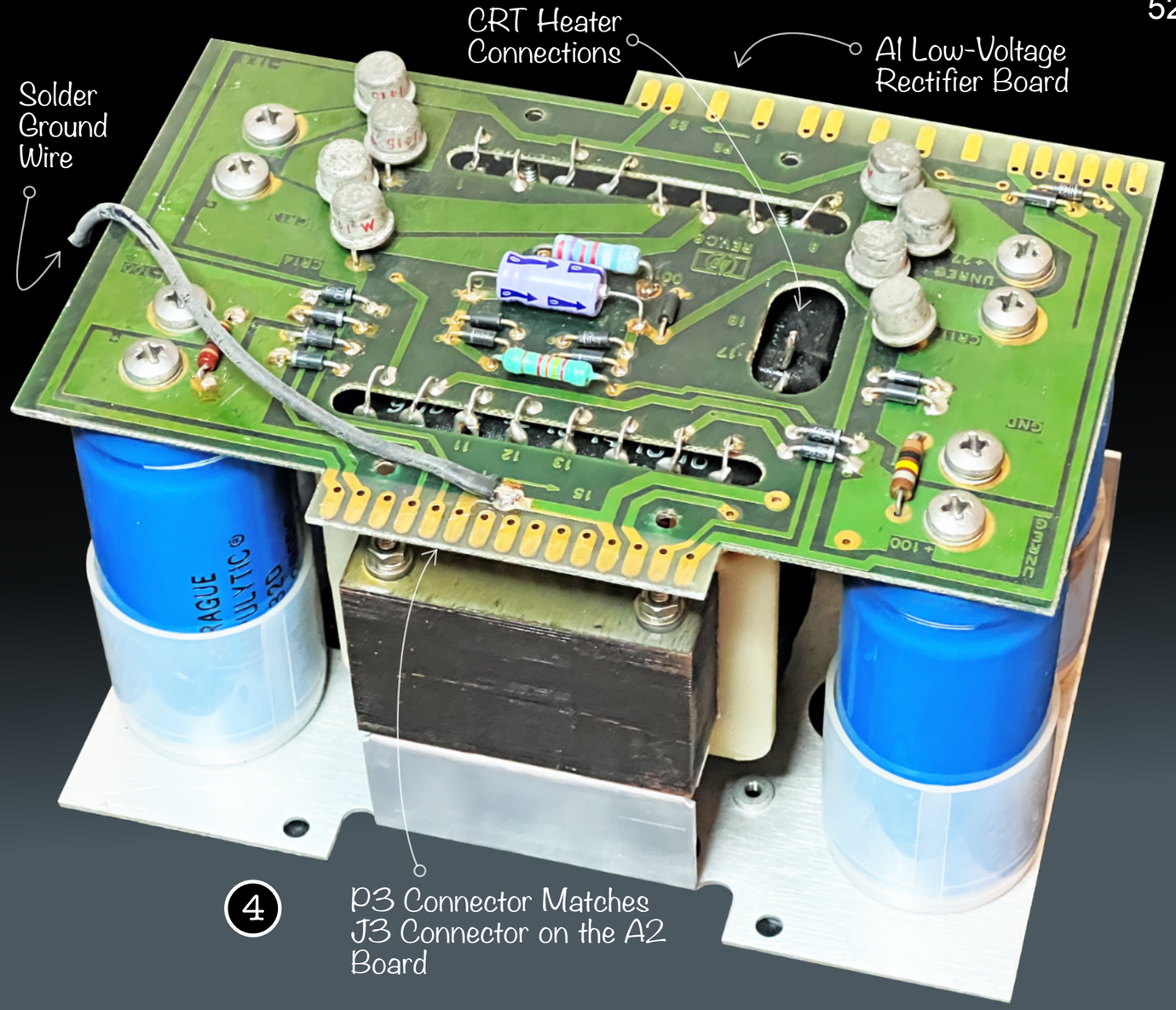
- almost all the old-style diodes you see in the photos were open. I imagined that it was due to the shorted capacitors, and this was the opportunity to check them, but the capacitors were all good. Probably an original defect?
- in the shock, two transformer connections broke (photo ❸);
- the power supply has three soldered connections; one to ground (photo ❹) and two for the CRT heaters (photo ❶). One of the latter was done badly by me and I had to disassemble again the power supply.



❶ The CRT heater soldered connections. ❷ The replaced 3A diodes. ❸ A broken transformer joint. ❹ The transformer assembly with the A1 Low-Voltage Rectifier Board.

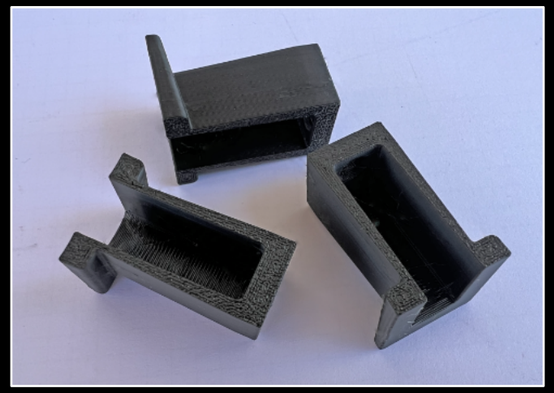






Fixed!

After all that above, I had the satisfaction of seeing the 181A returned to life. Several hours to clean it, and it shines not like new, perhaps, but almost.



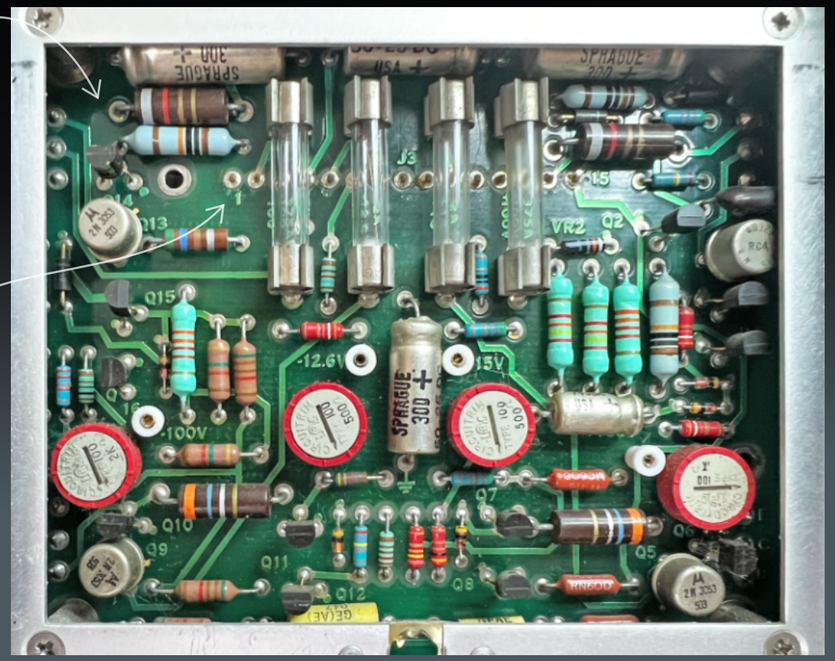
Feet

As you can see, the 180 lacked two rear feet. My son Marco came to my rescue with his 3D-printer. You can download the model he built for me from my web page.

In the photo on the right you can see the 181A's rear panel. It should be identical to the 180A, but in this case the 181A is newer and you can notice another small but important project evolution: the adoption of a IEC 60320 C13 connector for the 110/230V AC power supply, in place of the strange one used on my 180A, which forced me to build a rough mating female one.

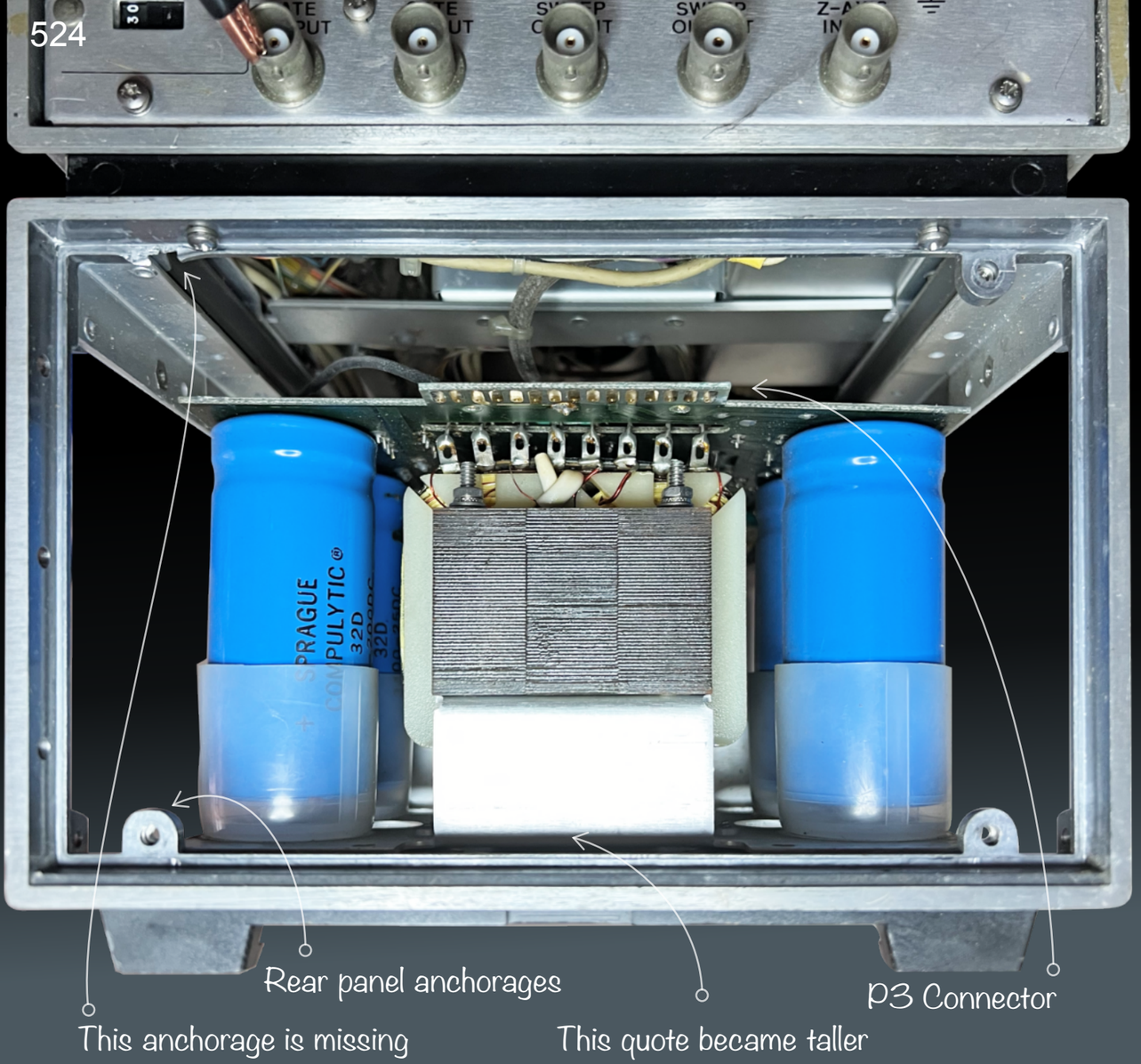
A2 Low-Voltage Regulator Board

J3 Connector Matches P3 Connector on the A1 Board





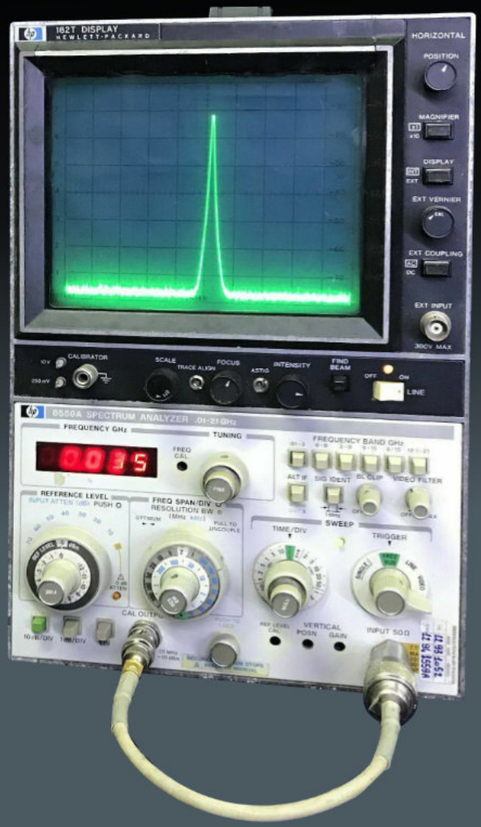
Door to Access the A2 Board



Other Valuable Tips

David has a deep knowledge of the 180 family, and gave me some other valuable tips:

- Metal Film Resistors: some of the metal film resistors used in the voltage divider/feedback circuits in the PSU and the horizontal amplifier can drift high in value, or go open.
- 4-071 Transistors: used in the older scopes do go bad occasionally, sometimes they also fail intermittently & drive me up the wall, trying to figure out which is to blame.
- PSU Over-Voltages: there was a warning of PSU over-voltage faults causing damage to some plug-ins; testing & repairing the PSU without the plug-ins installed is recommended.
- Rotary Switch Troubles: the newer timebase plug-ins such as the 1825A can suffer from the plastic edge of the rotary switches cutting through the PCB traces, I've seen this in other scopes, such as a 1715A.
- 182A: the “big screen” 182A doesn't have the internal flood gun in the CRT, it uses external lamps for illumination, later 182C & 182T use a CRT with the flood gun, it's slightly longer as a result.



On the left: my 181A clearly had received a strong shock. One of the four anchorages was completely missing and P3 connector level changed, making impossible to mate the A2 Low-Voltage Regulator Board J2 connector. Probably, the former owner had become discouraged and had given up on the repair.

On the right: the 182T oscilloscope in a spectrum analyzer setup (courtesy of Radio Surplus Elettronica).



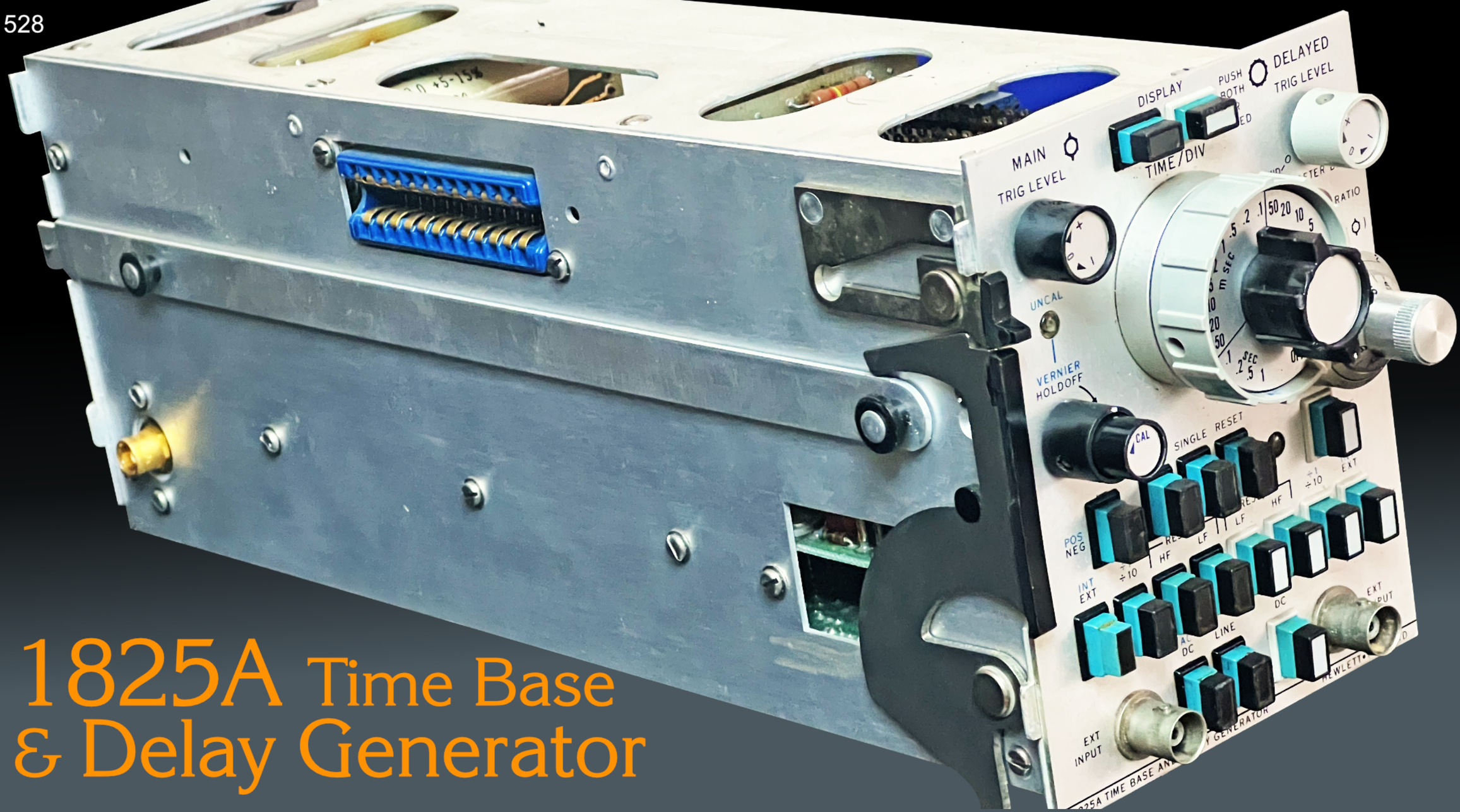
Section:

Oscilloscopes

Subsection:

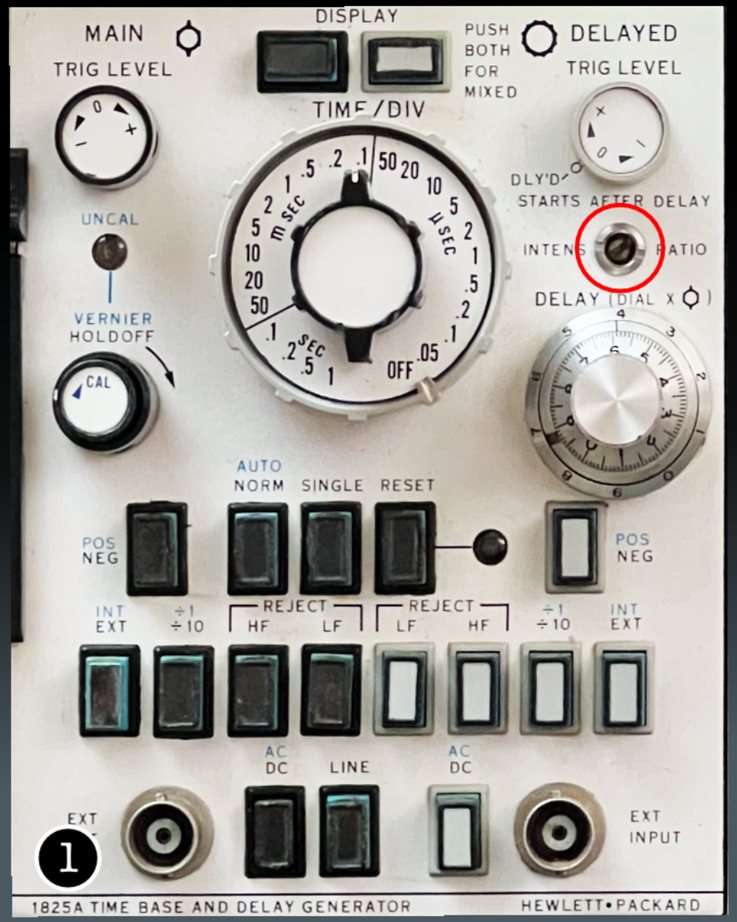
1825A Dual Time Base

Or, in accord with the HP denomination, “Time Base and Delay Generator”.



1825A Time Base & Delay Generator

1825A Time Base and Delay Generator



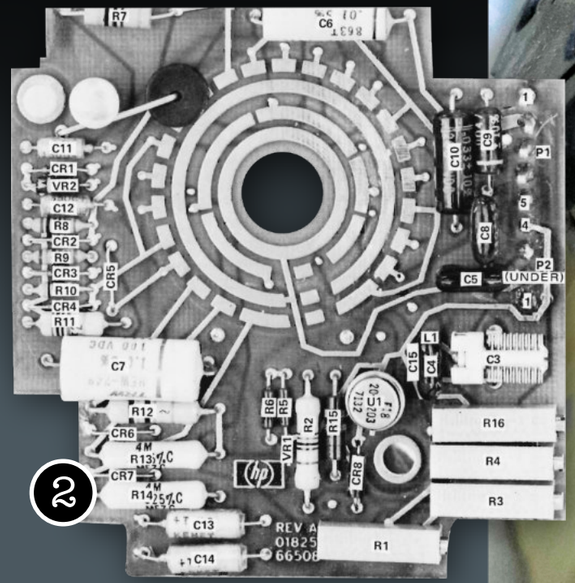
The Model 1825A time base and delay generator provided sweep speeds ranging from 50 ns/div to 1 s/div in 23 ranges. Delay times were continuously variable from 50 nanoseconds to 10 seconds and are accurate to 0.75% with extremely low jitter of 1 part in 50,000. Also, a calibrated mixed sweep mode was provided. The mainframe X10 magnifier increases sweep-speed capability to 5 ns/div with 5% accuracy.

The 1825A seems different from the original 1821A, and appears first in the 180-Series brochure, dated 15 October 1971, more than a simple face lifting of the original 1821A. It seems very well built and also the pushbuttons have still a good contact.

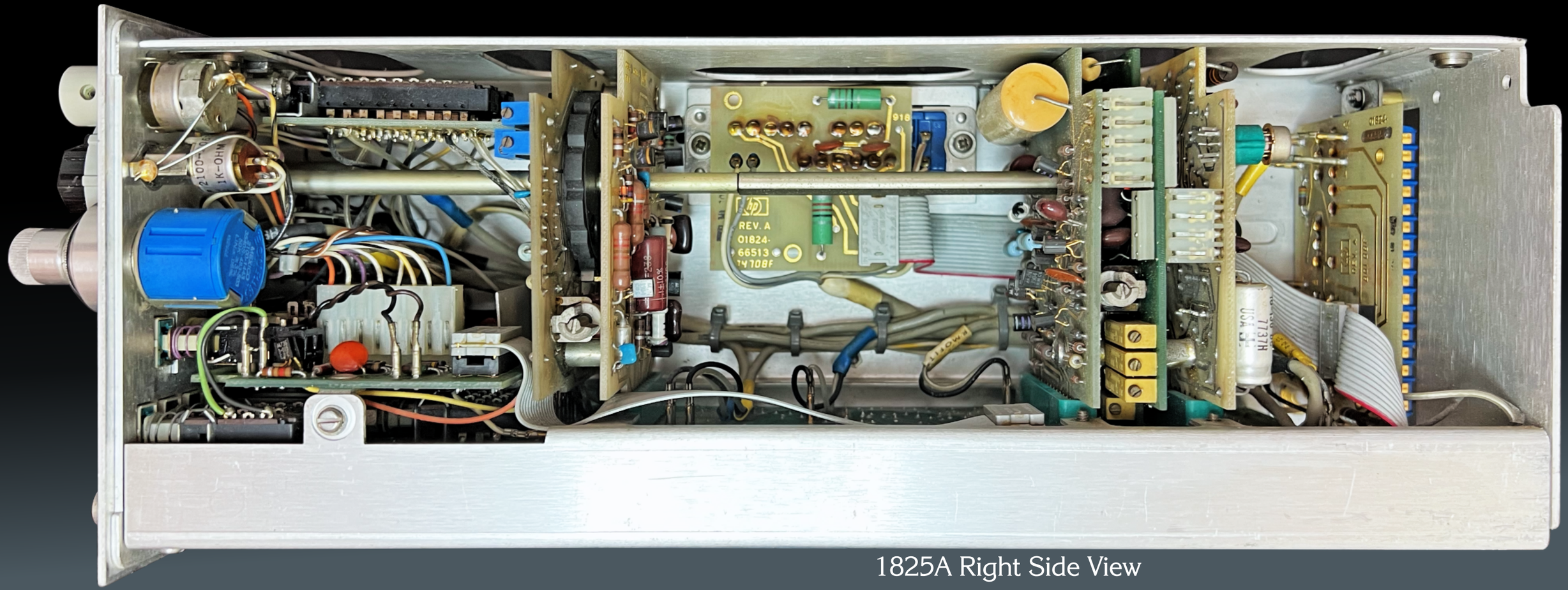
Note that the keys are not damaged by the time, as I thought before cleaning them, but are originally different in color, to distinguish them for the delaying and the delayed time basis. I appreciated the front-panel trimmer to set the different intensity of the two time sections (circled in red); this control is generally placed deep inside Tektronix 7000-Series mainframes.

Not bad the selector switches, implemented on the PCB as shown in the pictures. Differently from the Tektronix solution, the contacts are here self-cleaning, due to the attrition, and still work well enough in my 1977 unit.

❶ 1825A front panel, circled in red the trimmer to set the highlight intensity. ❷ and ❸ The selector switches are implemented directly on the PCB.



1825A Time Base and Delay Generator



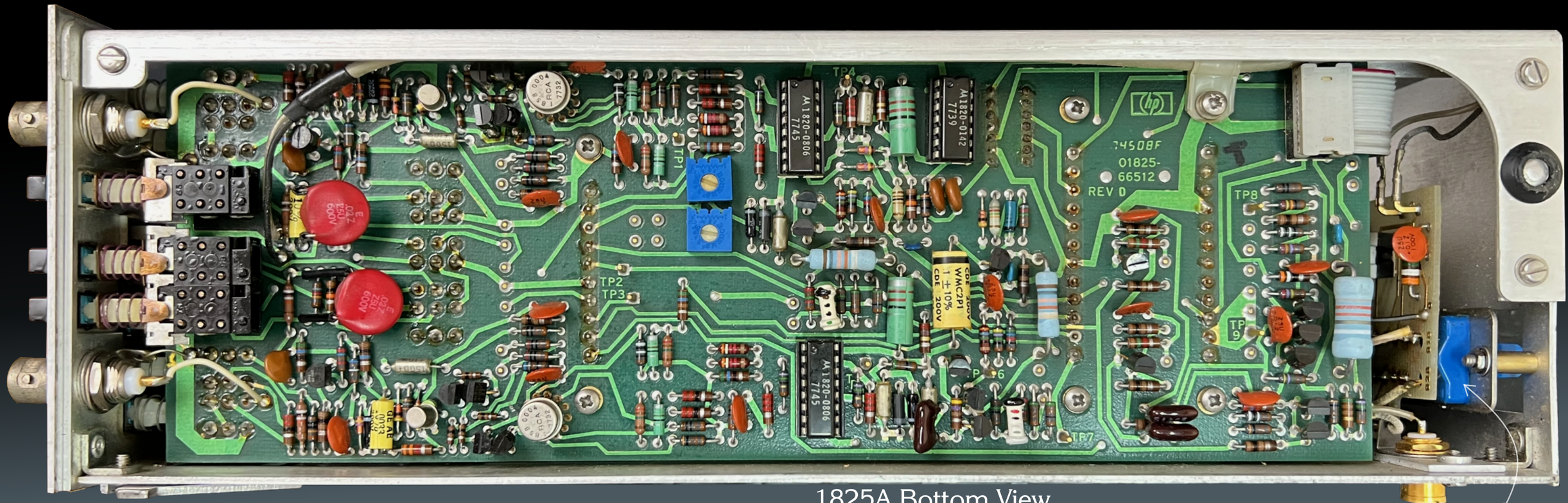
1825A Right Side View

1825A Time Base and Delay Generator



1825A Left Side View

1825A Time Base and Delay Generator



1825A Bottom View

P1 Connector to the Mainframe



Section:

Oscilloscopes

Subsection:

1806A Dual Differential

Officially denominated “100 μV Dual Differential (500 kHz)”

Differential Amplifier

1806A



I don't know why, but I particularly like differential amplifiers. Today they seems to be obsolete, but I find them indispensable in some circumstances, and I am not able to obtain the same results they allow with a modern scope, even in A-minus-B mode.

We talked a lot about differential amplifiers in the Tektronix 7000-Series book [2], and we saw that thanks to them, we can observe very small signals.

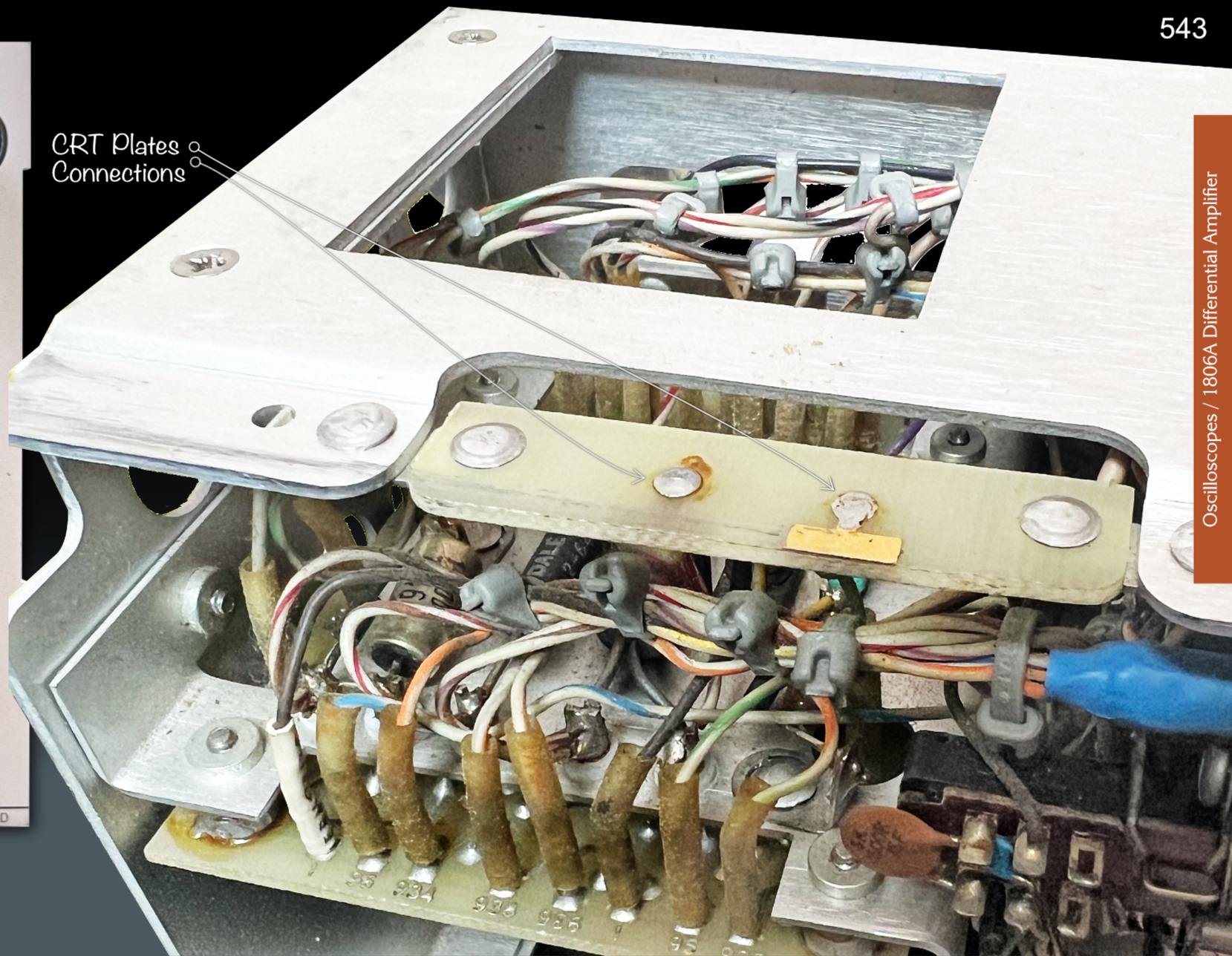
This 1806A was not very widespread, so much that I could not find its manual, neither by Artek Manuals.

Its specifications are not supreme but honest, with no special function; the bandwidth is 500 kHz and the maximum sensitivity is 100 µV/div. A key allows to reduce the bandwidth to 50 kHz, very useful with feeble signals.

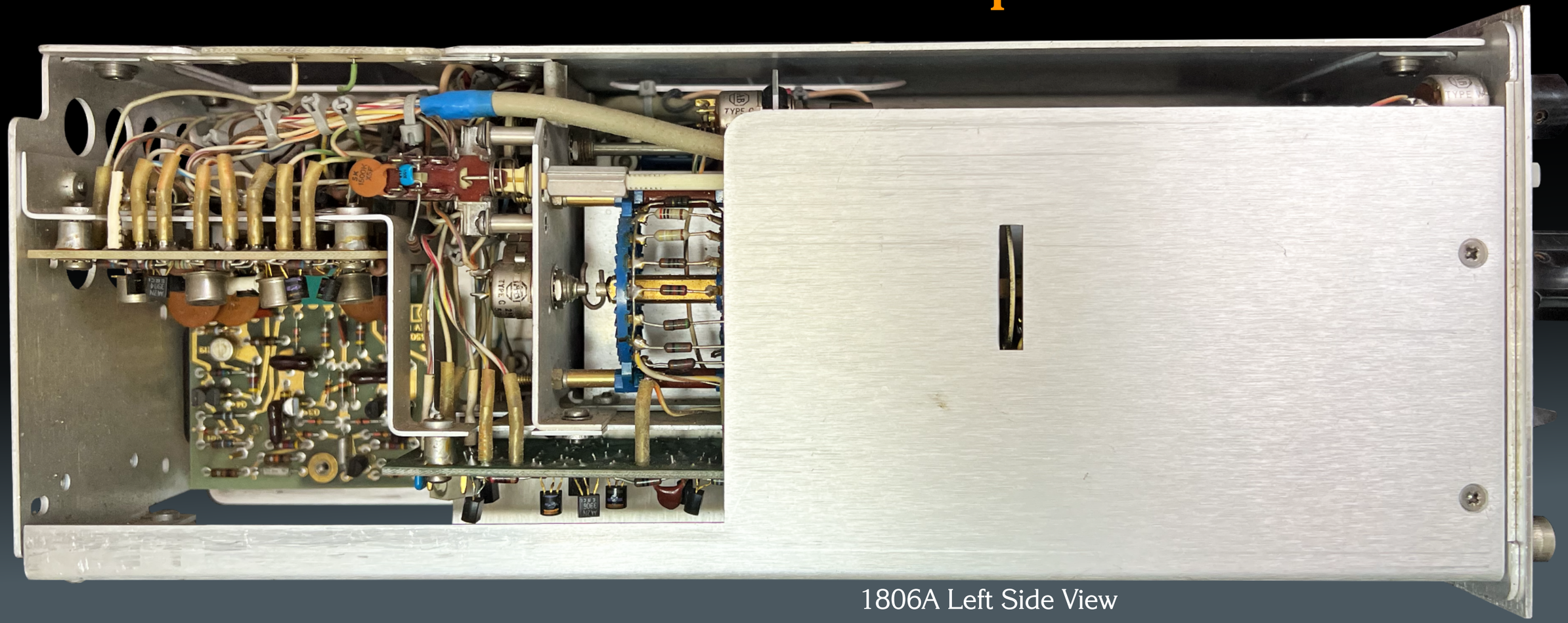
In return, compared to Tektronix models like the 3A9, 7A22 or 7A13, it is dual channel instead of single, a good benefit, especially if you consider that the 180-Series oscilloscopes have only two bays instead on three.


A
DISPLAY
TRIGGER SOURCE
B
POSITION
BAL
CHOP
ALT
COMP
BAL
POSITION
50
CAL
BW/kHz
CAL
50
BW/kHz
500
VOLTS/DIV
500
CAL
UNCAL
V/DIV
MV/DIV
CAL
DC
OFF
AC
DC
OFF
AC
DC
OFF
AC
DC
OFF
AC
+
INPUT
–
+
INPUT
–
1806A 100 µV DUAL DIFFERENTIAL (500 kHz)
HEWLETT • PACKARD

1806A

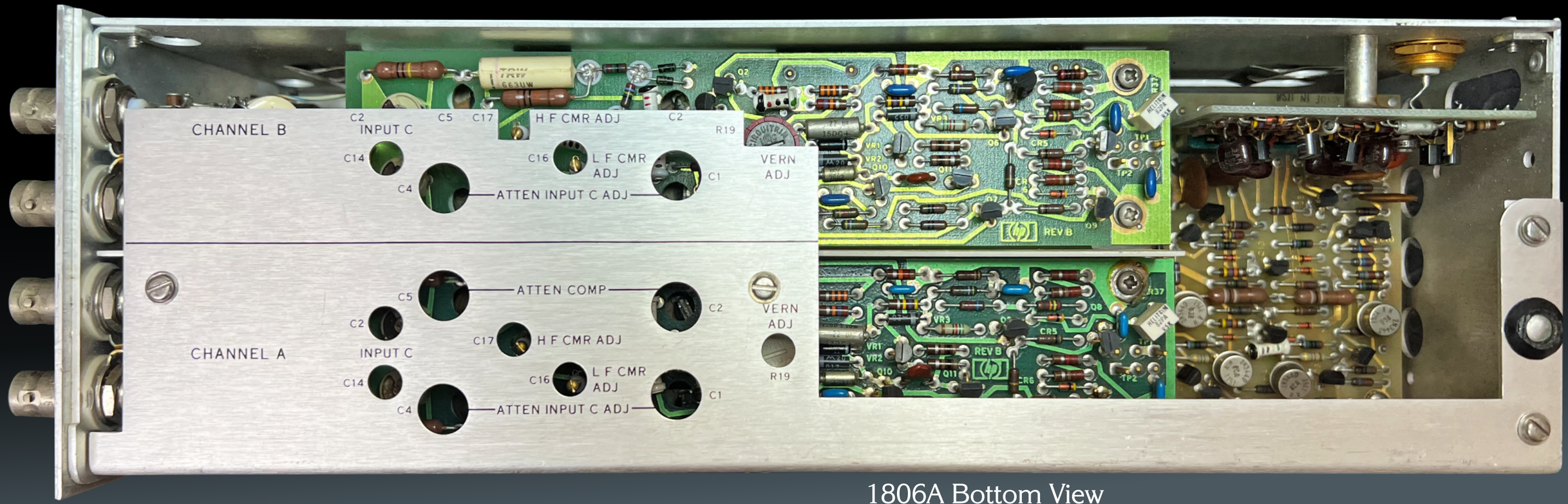

CRT Plates
Connections

1806A Differential Amplifier



1806A Left Side View

1806A Differential Amplifier



1806A Bottom View

Model 1806A is a dual channel, differential input amplifier for low level measurements in 180 system mainframes. Operating characteristics are: dc to 500 kHz bandwidth, 100 mV/div to 20 V/div deflection factors, 100 dB CMRR from DC to 10 kHz with a ±10 V common mode signal on the 100 mV/div range, and less than 20 µV of noise, measured tangentially at full bandwidth.

Conclusions

This with the HP 180 Series was a wonderful experience, where I was happy to spend several days of my time. The two units that I bought for few euros completely changed my perspective on this wonderful HP product line, which I thought to be copied from the Tektronix 7000s, and discovered to be instead the originals. Conceived before 1966, they set the tone for the near two decades in professional oscilloscope design.



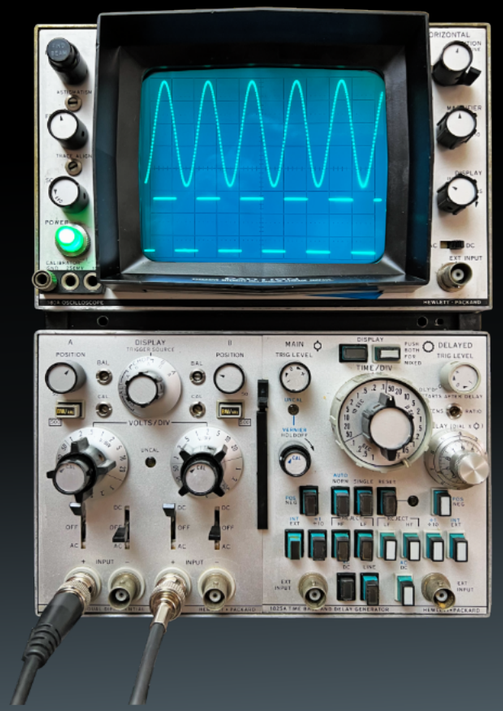
This is my helper. He is responsible for sniffing every square millimeter of the equipment I carry home. Very tired...

References

[1] Tektronix, Epic Oscilloscopes - Elektor Book International https://www.elektor.com/products/tektronix-epic-oscilloscopes

[2] Tektronix , the 7000-Series - free download from www.k100.biz

[3] The Great Hewlett-Packard - free download from www.k100.biz



Oscilloscopes

Subsection
54502A oscilloscope

Exploited and humiliated

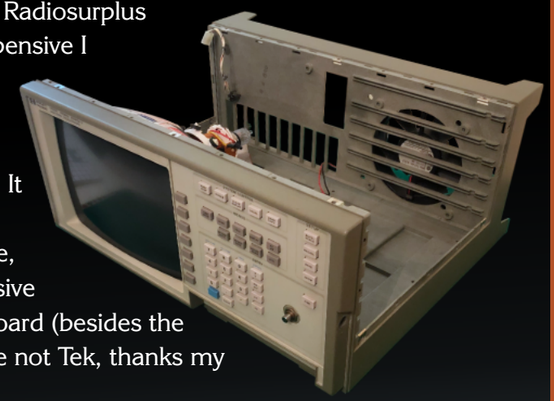
HP54502A

Exploited and humiliated

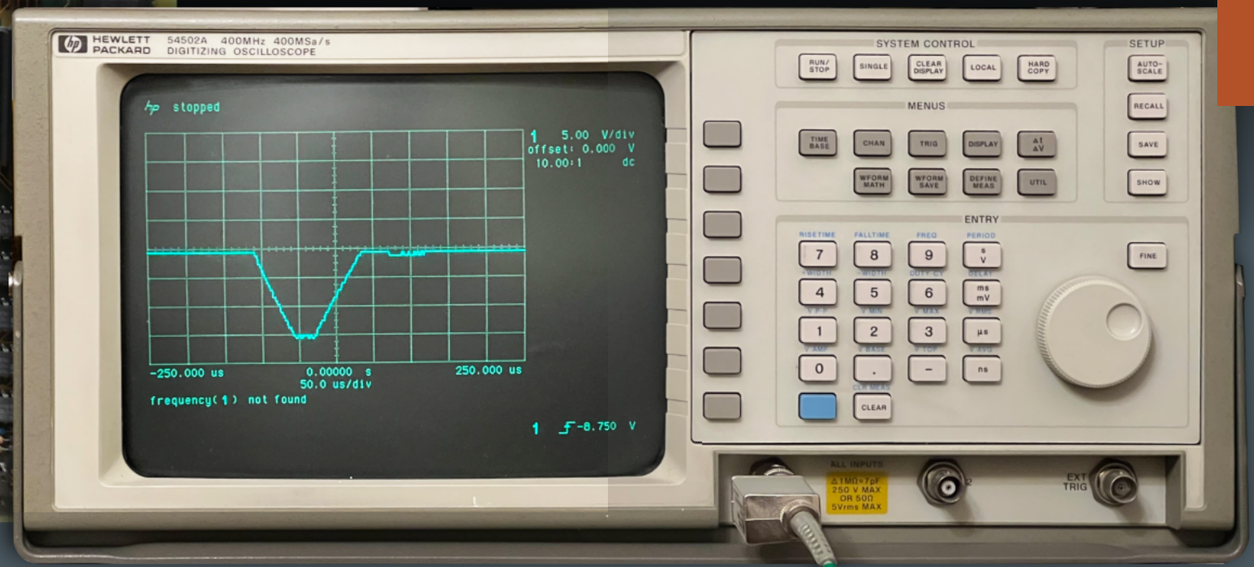


Besides TV like CRT, the 54052 is built on a not too much expensive single board, that resembles the coeval PC motherboards. Note the 68000 CPU, in its typical 64-pin package, and the Dallas memory, with built-in battery, rather common in those years. As told, had to replace it.

Really, the 54502A is not charming, and did not stay long in catalog in a period when HP was constantly introducing new models. Introduced in 1989, completely disappeared from the 1993 catalog. In 1990, it costed 3,465$, i.e., 8,073$ today. However, it was essential fixing the first Tektronix scopes (today I confess that I use more often the more modern 54540A or the Tek 2445B for its embedded universal counter and because it is analog; an analog scope gives you more feeling about the incoming signals).



I bought years ago the 1989 54502A from Radiosurplus Elettronica, just because it was the less expensive I could find. Years later, it required a repair to replace the NOVRAM chip, which included a lithium battery, now exhausted, and that was the only problem it gave me. It must admit that it is not a bad beast: 400 MHz (repetitive), 400 MSa/s, dual time base, easy to use and a very simple and inexpensive physical architecture, with just one large board (besides the CRT and the power supply). Even if you are not Tek, thanks my old 54502A!



Oscilloscopes

Subsection
54540A oscilloscope

The most modern stuff here among all

An easy winner

HP54540A

1993

I bought this oscilloscopes ten years ago and than forgot it. To write this book reminded it to me, so I went to seek it, I found it and I thoroughly cleaned it to photograph it for you.

From a mere technical point of view, it's the best of all here described, but it is not fair. It was presented in 1993 and so it wins easy: 4 channels, 500 MHz, 2 GSa/s (8 bit), 2 mV, 32k points, FFT.

The 54540A disappeared from the catalog in 1998. I have got no information on its price.

It claims:

- sequential single-shot to capture successive single-shot events without capturing the dead time in between;
- glitch trigger to trigger on glitches down to 1 ns wide;
- FFTs to identify signals, determine signal fidelity, or to analyze high-speed transients in the frequency domain;
- templates for pass/fail testing;
- 23 automatic waveform parameter tests. Incoming waveforms are measured with up to three tests at a time and passed or failed according to their limits;
- waveforms can be saved and time-stamped upon failure of either waveform compare or limit test. Up to 665 failures of 500 points each can be stored in multiple memory and sent to a printer, plotter, or a computer via HP-IB.
- peak detect to avoid missing narrow down to 1 ns events at slow sweep speeds.
- 3 1/2-inch, 1.44 MB, floppy disk drive.

Other features include advanced logic triggering, automatic setup, hardcopy output, full GPIB programmability, pre-trigger viewing, TV triggering, voltage and time markers, pan and zoom, user-controlled sample rate independent of sweep speed, user-controlled record length, fast update rate, fast overdrive recovery, and more.

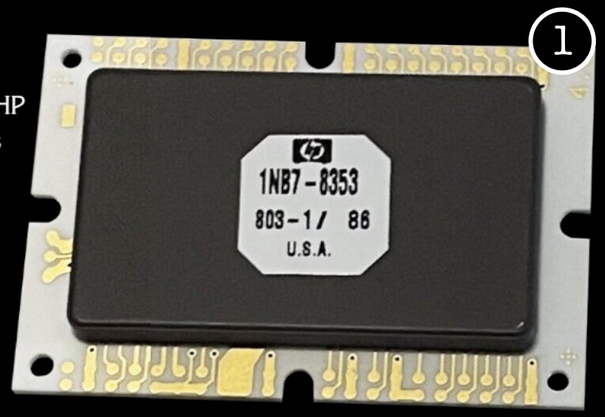
The 54540 menus look and feel resembles strictly the 54502, but with a big difference: knobs begin to reappear on an oscilloscope panel; just six, in this case, but they announce a trend inversion for the subsequent years, and they make working much more comfortable.

I have found disappointing the lack of the window function, present in the 54502A but only in a "fake" way (just graphic expansion), but the thing I like less in it is the fan noise, …a small airplane!

The user interface of the 54540A

HP product system

Used to the first years Tektronix clarity, I find that the HP product system is rather confusing, with lot of models with rather similar identifiers, the differences of which are not always clear, or, willingly or less, hidden it the catalogs folds (for example, the missing window function compared with the 54502).



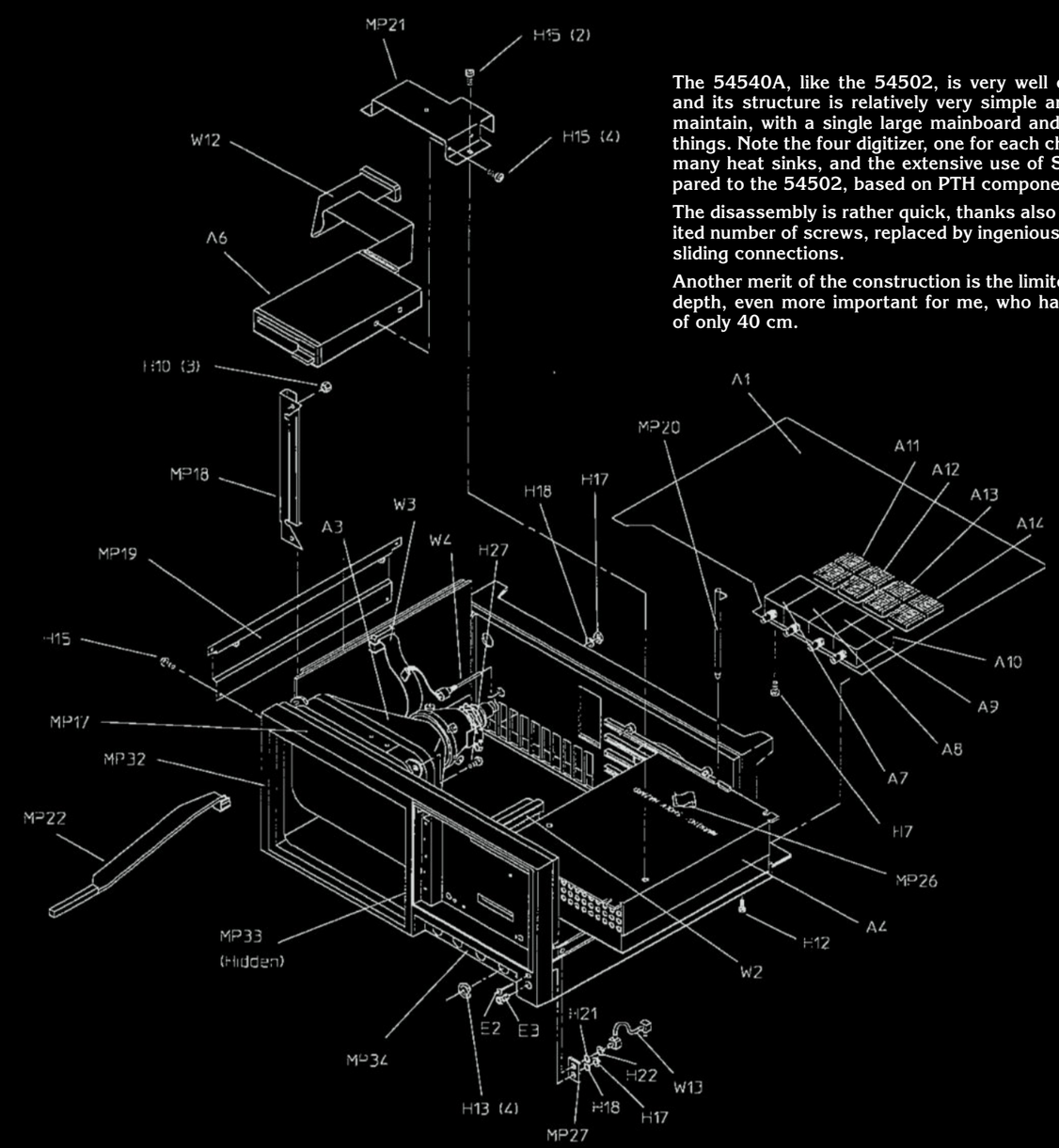
For example, in 1997, the 54540A had as many as seven companions: 54540 C, 54542A and C, 54520A and C, 54522A and C, the differences of which I am not able to synthesize shortly.

Besides these small flaws, the great Hewlett & Packard left us many instruments like this, that I find beautiful, easy to use, fast and rich of functions.





❶ One of the four 54540A hybrid 2 GSa/s digitizers. ❷ The rear of the 54540A is very crowded, as it happens for most oscilloscopes. RS-232, GPIB and Centronics interfaces were a must in those years. ❸ The charm of a magnetic CRT will never be comparable to electrostatic ones. Furthermore, in this case, the (not declared) resolution is not exciting.



The 54540A, like the 54502, is very well engineered and its structure is relatively very simple and easy to maintain, with a single large mainboard and few other things. Note the four digitizer, one for each channel, the many heat sinks, and the extensive use of SMD, compared to the 54502, based on PTH components.

The disassembly is rather quick, thanks also to the limited number of screws, replaced by ingenious joints and sliding connections.

Another merit of the construction is the limited housing depth, even more important for me, who have shelves of only 40 cm.

The case of the missing window

Too hastily, I wrote something wrong in the previous pages. I said:

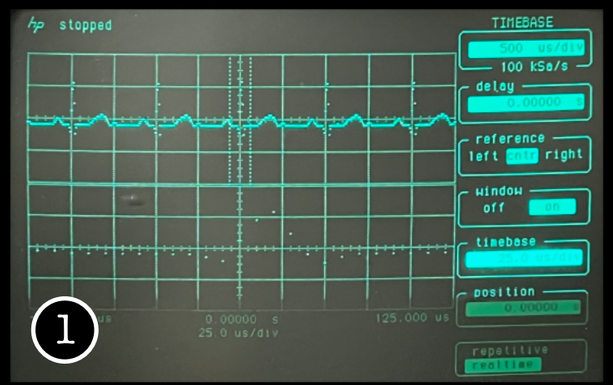
- the 54502A has the window function, similar to the delaying/delayed function of analog scopes;
- the 54540A has not this function.

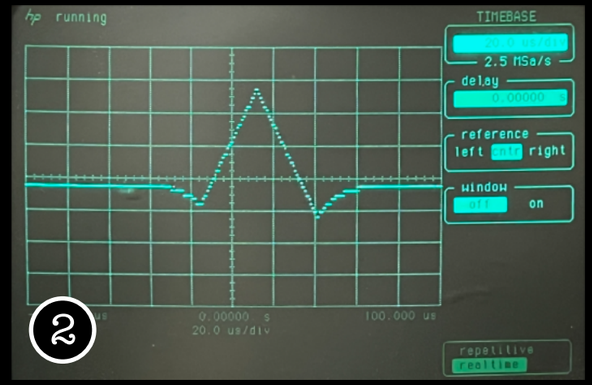
The reality is:

- to make a real window function, two time bases are required;
- neither the 54502A, nor the 54540A has two time bases;
- the apparent window function on the 54502A it's a fake. It is just the graphical expansion of the stored points data buffer.

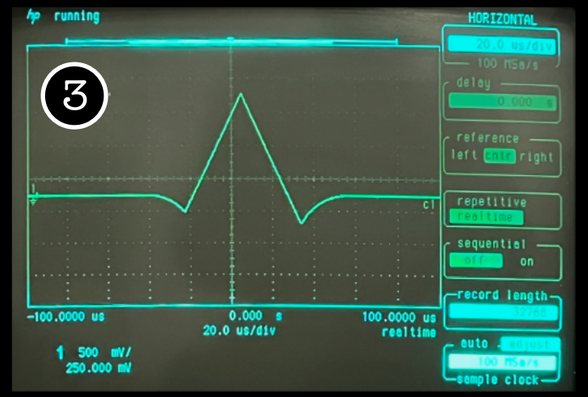
As a confirmation, see the 54502A photos herein reported. Photo ❶ shows the incoming signal, in the upper panel, and the zoomed signal below. Note the intelligent way to show the zoomed portion, that in 7000-Series would have been highlighted, with two dotted vertical bars. I willingly decided to remove the dot join mode, and so you can see that the zoomed trace is composed by very few points.

With a true delayed time base, the zoomed trace should be about like photo ❷, scanned at 20 us/div.





❶ The incoming signal scanned at 500 µs/div with the window function activated, at 25 µs/div. The lower trace, with a low number of points, reveals that it is really only a graphic zoom. ❷ The same pulse how would it be with a true delayed time base. ❷ Same screenshot on the 54540A, with frame buffer at 32,768 and 100 MSa/s sample rate. The chromatic alterations are due to the iPhone photo camera that does not get along with the screen refresh.



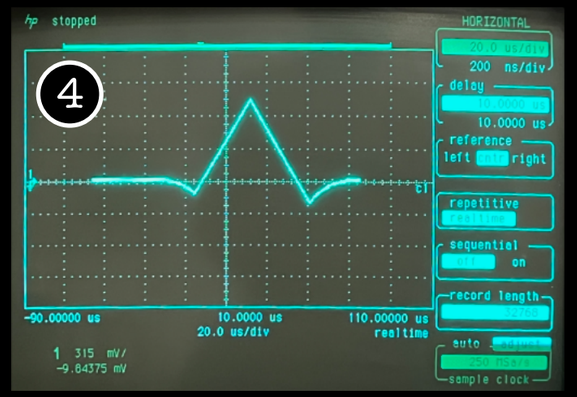
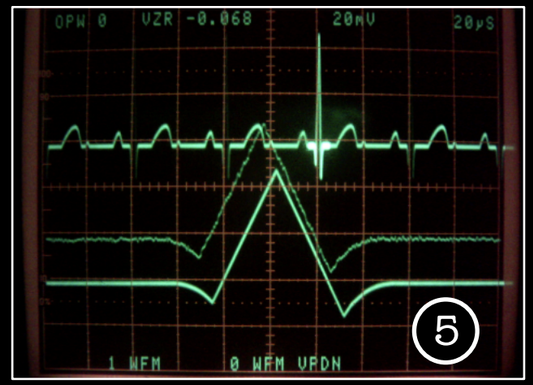
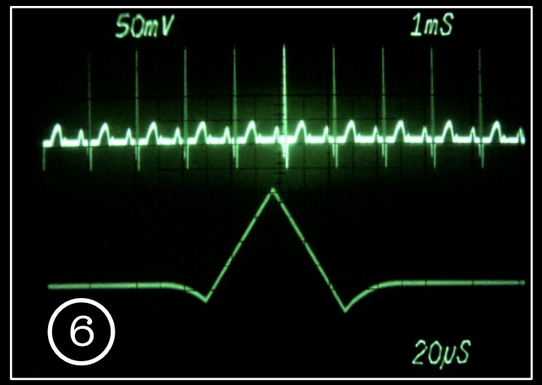


Photo ❸ shows the same pulse on the 54540A, manually setting the buffer size to 32768 and the sample rate to 100 MSa/s (these parameters are automatic and cannot be set on the 54502A). Also here the dot joining has been disabled, but the points are so many that there is no gap between them. As logical, raising the sample rate to 250 MSa/s, the trace does not fill the whole screen (photo ❹), because the memory buffer is not large enough.

To complete the pictures and leave you more historical information, here below the same pulse analyzed on the digital/analog Tektronix 7854 and on the CRT storage Tektronix 7633.





❸ Same screenshot on the 54540A, with frame buffer at 32,768 and 100 MSa/s sample rate. ❹ The 32,768 point long memory buffer is not enough to fill the screen at 250 MSa/s. ❺ The same pulse on the 7854 in analog mode, with superimposed the digitalized trace. ❻ The same pulse got on a Tektronix 7633 CRT storage oscilloscope.

Counters

This term is not used in Italian. We call them frequency meters.



Section:

Counters

Subsection:

Measuring Frequency

Some small talks about frequency measurement in general.

Measuring Frequency

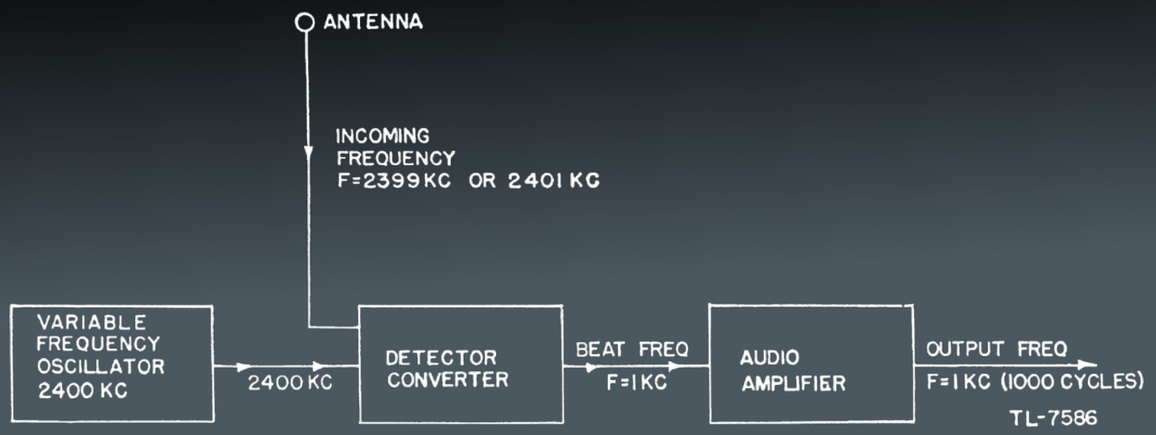
Precisely measuring the frequency of an alternate, repetitive signal is today one of the simplest operations; you can do it with a digital counter or with an oscilloscope. For low frequency, even many VOMs can solve your problems.

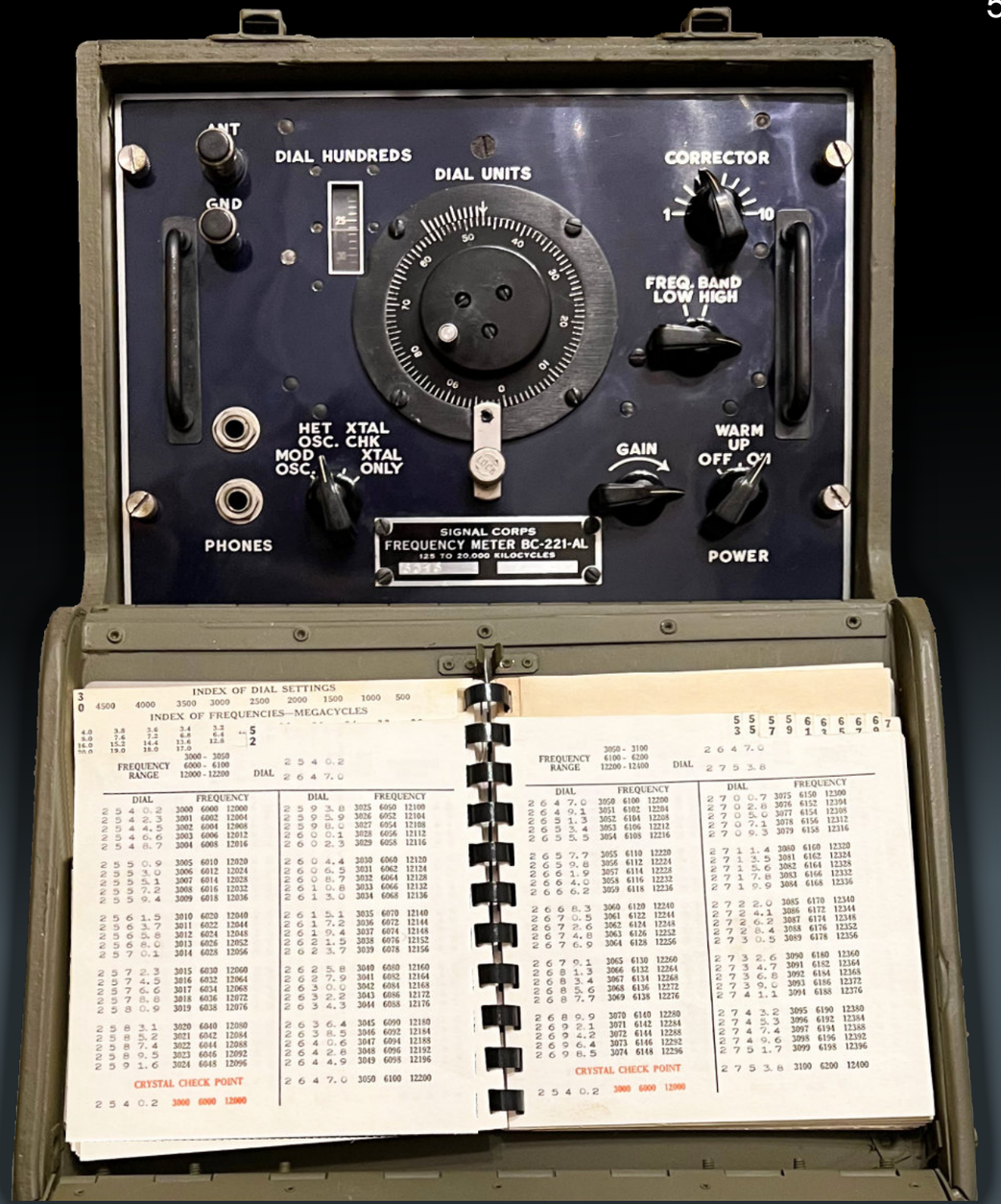
In the past it was not so easy. The easiest way to measure a frequency, is to use a capacitor in series with a voltmeter. The higher the frequency, the lower is the capacitive reactance of the capacitor and so the voltmeter moves more, but certainly the scale will be non-linear and the accuracy low.

The BC-221

The first time I read the words “frequency meter” was probably in a magazine ad for to the military surplus BC-221 from 1941 (photo on the left), very common in the sixties, at least in Italy, but at that time I had not a clear idea of how it could work.

Later, I discovered that its principle of operation is simple: as shown below, the BC-221 is essentially a wide band receiver and a Variable Frequency Oscillator (VFO). It allows to listen the beat of this oscillator and the unknown signal. The VFO is not only highly stable, but individually calibrated.





An individually-compiled book contains the frequency for each VFO's control position, and constitutes an integral part of the instrument. You get the zero beat in the headset, and read its corresponding frequency. In reality, you needed to know at least approximately the signal frequency, because you could be beating a harmonic of the BC-221 or of the unknown signal; nevertheless, it was a good instrument, and most of them have incredibly kept their stability and accuracy over the years (80 and more…). I own two of them and I can confirm that.

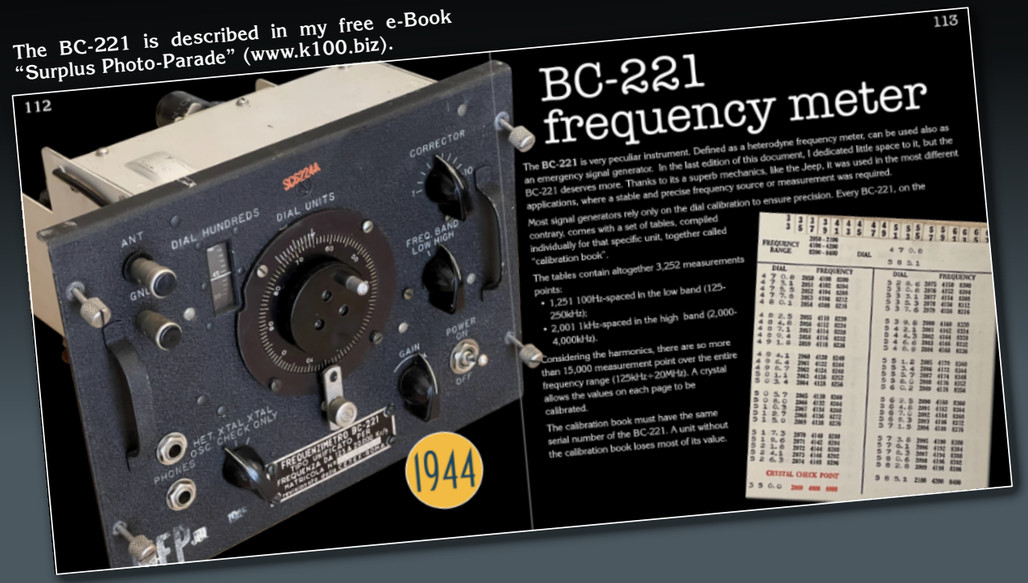
The BC-221, within its limits, is still today essential in some cases, because it doesn't load the circuit under measure almost at all. If you want to read the frequency of an oscillator, for example, you just lean the BC-221 antenna in proximity of it and can silently get a precise measure of it.

The BC-221 is described in my e-Book "Surplus Photo-Parade" you can download from my web page (www.k100.biz).

HP 500 Frequency Meter

One of the first HP frequency meters was the Model 500 you can see here on the right in its B version. It directly measured the frequency of an alternating voltage from 3 Hz to 100 kHz.

The BC-221 is described in my free e-Book "Surplus Photo-Parade" (www.k100.biz).



HP Model 500B (courtesy of www.istitutomontani.edu.it)

Suitable for laboratory and production measurements of audio and ultrasonic frequencies, it also was used for direct tachometry measurements with a suitable transducer (version C).

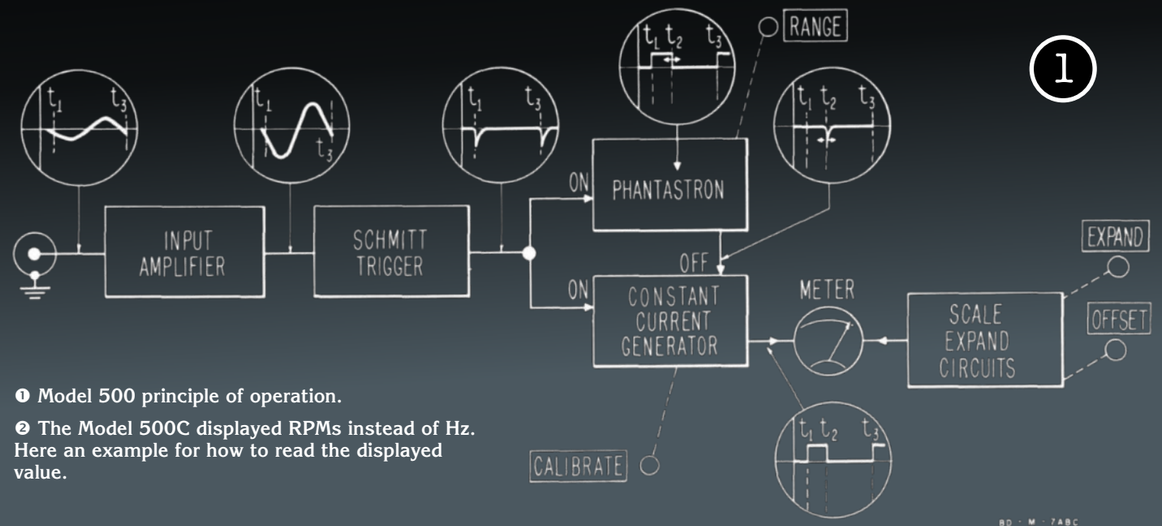
Readings on the 500B were not affected by variations of input signal level or power line voltage. The meter counted sine waves, square waves of pulses and also the average frequency of random events.

The Model 500A had been the very first occurrence of an electronic device to measure frequency and was introduced by HP only 3 years after the company's creation. It was a natural complement to the early Hewlett Packard audio oscillator production.

The Phantastron

The 500B used non-trivial solutions; among them a Phantastron, which I thought it was a joke from a Donald Duck story, and instead is a real circuit used in Radar applications (see the box “The Phantastron”).

A Phantastron is a special type of an astable multivibrator with very precise timing which had special significance for the timing in ancient analog radars. It was invented in 1942 during radar development in World War II by the British engineer Alan Dower Blumlein



❶ Model 500 principle of operation.

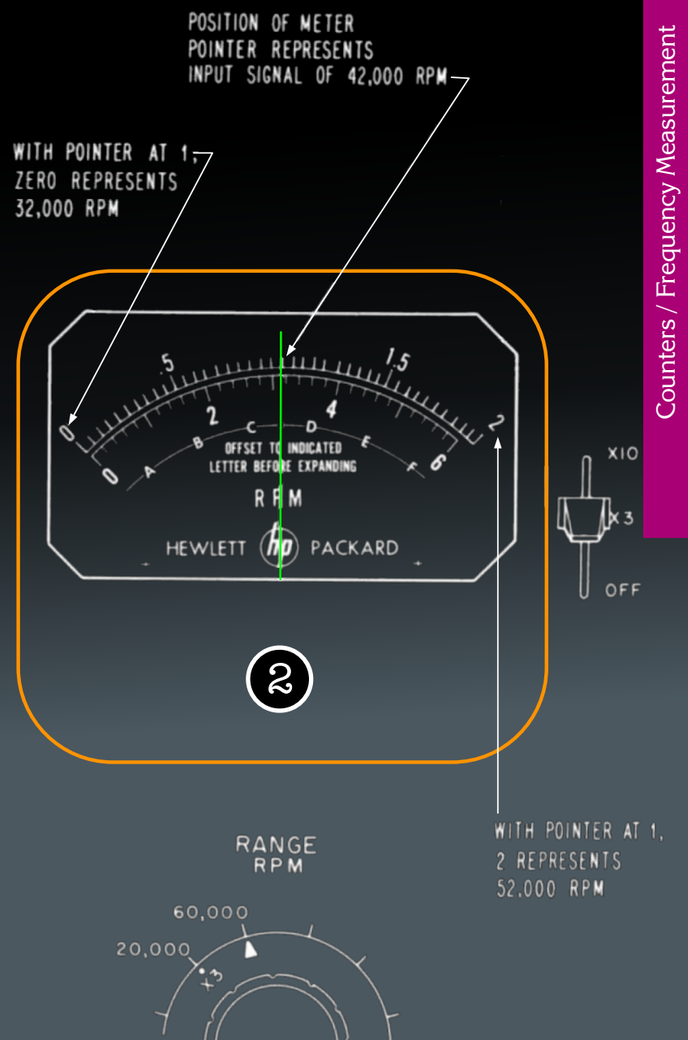
❷ The Model 500C displayed RPMs instead of Hz. Here an example for how to read the displayed value.

Whereas a multivibrator derives its timing waveform from an R-C circuit, the Phantastron uses a basic Miller-type sweep generator to generate a linear timing waveform, rather than the exponential waveform developed by the R-C circuit of the multivibrator. Thus, the output waveform is a linear function of the input (control) voltage, and the timing stability is improved. This d-c voltage allows a remote control of the duration of the gates (we find its declinations more times in many HP products).

The Phantastron circuit was used to generate a rectangular waveform, or linear sweep, whose duration is almost directly proportional to a control voltage. Because of its extreme linearity and accuracy, this waveform is used as a delayed timing pulse, usually in radar or display equipment. It is also used to produce time-delayed trigger pulses for synchronizing purposes and movable marker signals for display. For example it is used as a time-modulated pulse, to indicate antenna position at any instant of rotation, or as a range strobe or delay marker [from https://www.radartutorial.eu].

Phantastron action allows to develop a current pulse which is stable in length. At the same time, other parts of the 500 causes the current pulse to be stable in amplitude. As shown in the diagram on the left, one such stable pulse is passed through the meter circuit for each input cycle. The meter averages the pulses it receives and presents an indication proportional to average frequency.

As shown on the right, reading the pointed value was not as easy as saying “read”.

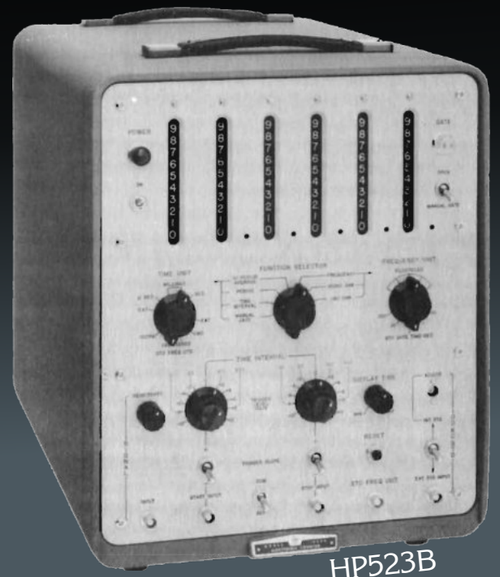


Counters

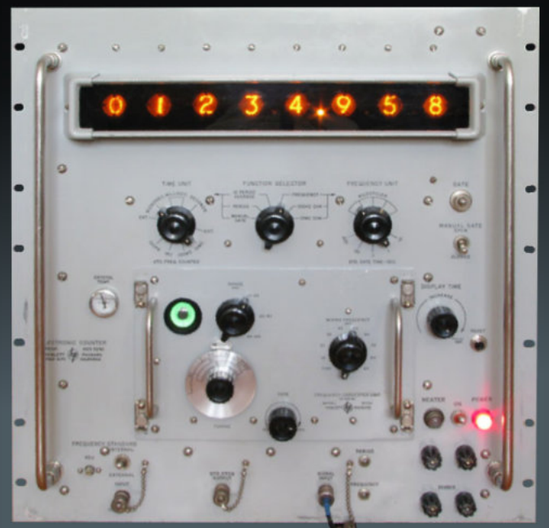
From the BC-221 and the Model 500, we can summarize that they are not what one could wish. Our desire is to read directly the frequency value. Something like that already existed in the fifties: if you want, also a radio receiver like the Collins R-392/URR shown in the photo on the right, with its digital readout could be considered a digital frequency meter, but you had however to manually tune the signal, whilst we want that the frequency meter itself could show the reading automatically and quickly.

The answer is the Counter: a device capable of measuring a frequency and show its value. Also in this field, HP taught the world the right direction. Just as the 1940s HP leadership in audio instrumentation was triggered by the Bill Hewlett's 200A oscillator, the 1951 HP 524A frequency counter would be the second "big success" product, starting the very long HP leadership in frequency measurement.

After WWII, the atomic energy business was big time and require precision counters. After an initial 520A which didn't reach great commercial success, HP became the industry leader in electronic counting, in the early 1950's, with the 524A frequency counter, which boasted a 0.01 cps to 10 "mc" measuring range. (Hertz came a little later).



HP523B



HP524C (retouched from madrona.ca)



The 521A introduced in 1955 was the first occurrence of a moderately priced, small size frequency counter. $475 for 12 Kg to be compared to the $2,500 and 55 Kg of the 524B open the field of frequency measurement out of the lab.

The Nixies Arrive!

These models had ten lamps for each digit; later the Nixies arrived, making these devices to assume the modern look. In 1959, the 524C replaced the difficult to read, vertical column, neon lamp display by a full 8-digit bright, big-numbered, in-line Nixies readout, with automatic illuminated decimal point

As the last improvement of the 1950s, the Model 523C was introduced in the 1959 catalog. It was the first of a category which came to named Universal Counter some years later. It went well beyond the simple measurement of electronic signal frequencies, it easily measures period, time interval, phase delay, random events and ratios.[freely resumed from hpmemoryproject.org].

Model 5315

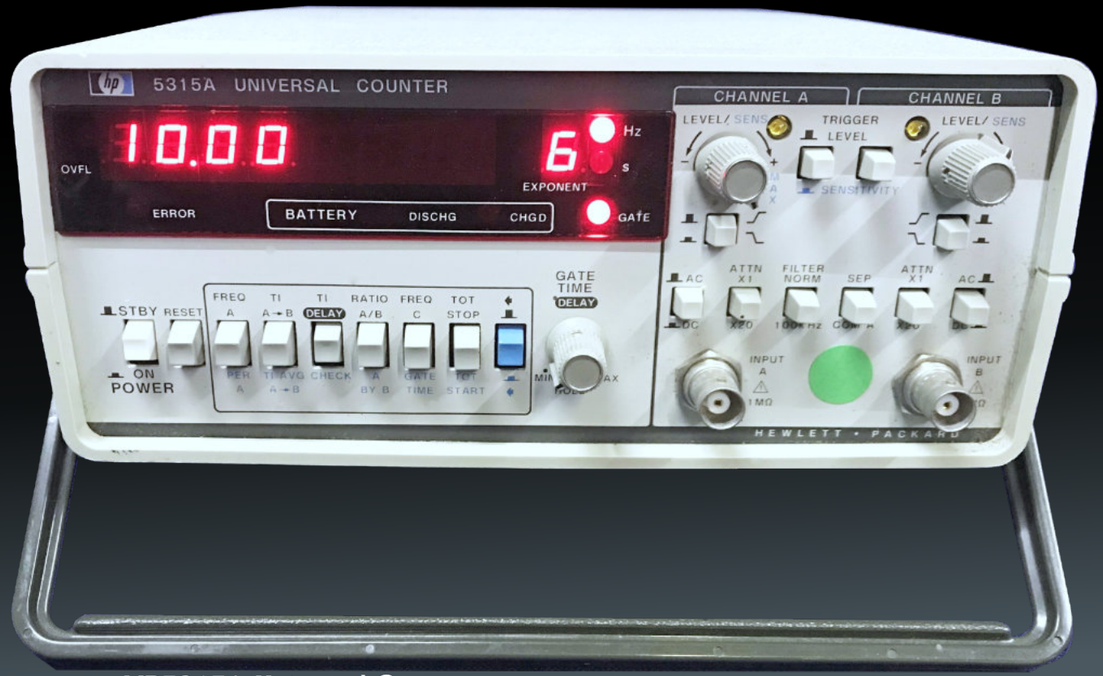
With a jump in our accelerated time machine, we arrived now to the relatively modern 5315A shown here in the big photo, which was the mother of the counters we present here, i.e., the 5316B and the 5335A.

Why was it so important? For example, because it introduced the Multiple-Register Counter chip (MRC).

The MRC Chip

At the beginning of the eighties, microprocessor head broadened performance capability in many new counter products. Intricate computing abilities became so readily obtainable in commercially available microprocessor chip sets. However, those microprocessors alone couldn't carry out complex counting functions. In addition to the processor unit, various circuit elements, both digital and analog, were required to accept, store, and regenerate data for different phases and different types of measuring functions.

HP decided to implement all these circuit elements in a custom bipolar LSI chip known as the Multiple-Register Counter (MRC) to develop a new generation of microprocessor-controlled counter products. Except for the controller (microprocessor), the display circuitry, the signal input amplifiers,

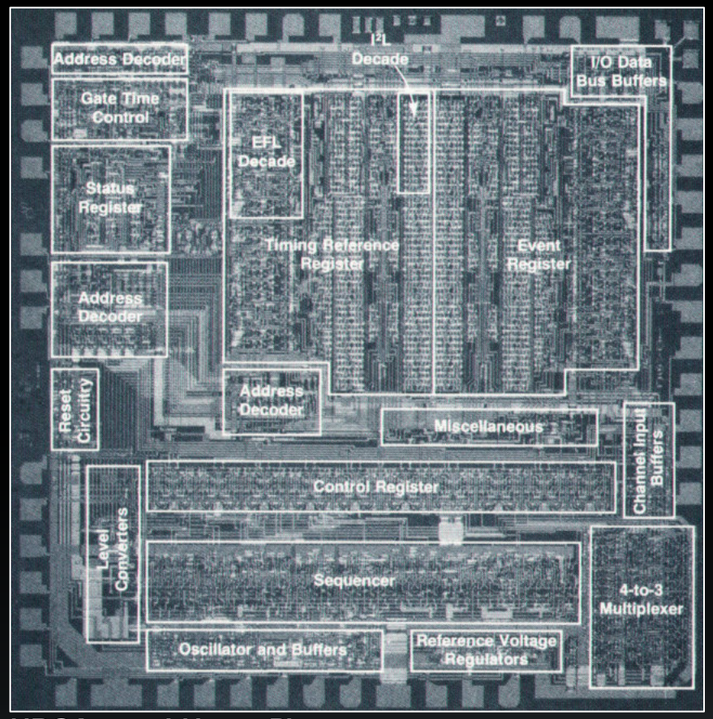


HP5315A Universal Counter

and the instrument power supply, all of the circuits required to perform all necessary counting functions were included in the MRC chip.

The decision to implement the MRC chip in the bipolar LSI process was mainly based on three factors:

- First, the process can accommodate mixed logic families with divergent performance characteristics, namely emitter function logic (EFL) and integrated injection logic (IL).
- Second, the process can accommodate miscellaneous circuit configurations, both digital and analog.
- Third, the dual-layer metallization feature of the process provides an efficient means of solving the complex high-density logic interconnection problem.



MRC Internal Macro-Photo

We will talk again of the MRC describing the specific products.

In the Following Subsections

In the following subsections we will try to describe the 5316A/B and the 5335A Universal Counters. I was unsure which to put first, but I discovered that both were introduced in 1980, so I decided to follow the order in which I purchased and described them: first the 5316, then the 5335.

Don't Waste These Masterpieces!

These instruments are valuable witnesses of our story. Never try to apply modifications to them; keep them clean and in the most original state. Try to repair/restore them with the respect due to a work of art.
Never cannibalize them to get and sell spare parts for more. In few word: love them!







Section:

Counters

Subsection:

5316B Universal Counter

"HP's economical 5315A/B, and 5316A counters provide all the universal counter capability you've come to expect at much higher prices..."

The HP model 5316B is a universal counter, measuring signals over a range of DC to 100 MHz. It measures Frequency, Period, Time Interval, Time Interval Average, Time Interval Holdoff (delay), and Ratio. A Totalize function with manual or external gating is also provided. All measurements except Totalize are displayed in engineering notation with up to eight digits of resolution. In addition, the HP 5316B may be programmed via GP-IB.

Two independent input channels are provided for time interval measurements. Each input channel has an Attenuator (X1, X20), Trigger Slope selector, Trigger Level/ Sensitivity control, three- state trigger lamps, and front panel Trigger Level Monitoring jacks. A front panel selectable Low-Pass Filter is provided for Channel A.

5316B Universal Counter

1980 (5316A)



The unit here presented is from 1977.

“Good Performance, Affordable (?) Prices”

Light and rather small (at least from the panel point of view), the 5316B offered good performances at affordable prices. Introduced in September, 1980, became the B version in 1988 with apparently little differences. The 5316A/B was the “professional version” of the portable 5315A, which had not the GPIB interface. Well conceived from the start, it remained in catalog until 1997, totalizing 18 years on the market, a real success. The unit here depicted is from 1994.

In 1981 was priced at 1,500$, thus 5.535$ today. It become 1,845 in 1993 (I have no later information), i.e. 3,874$ today (2023). So the price really dropped over the years, but was however rather high.

The MRC

As we anticipated earlier, a unique custom LSI-circuit called MRC (Multiple-Register Counter) packs counting and computing power into this popular counter series. Reciprocal counting techniques provide outstanding frequency resolution of 7 digits per second even at low frequencies. The continuously adjustable gate time allows automatic selection of sample size for easy trade-offs between measurement time and resolution.

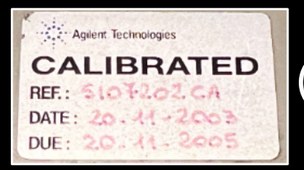
Functions

The MRC counters measure frequency to 100 MHz for CW and pulsed RF signals as narrow as 60 ms. Three time-interval measurements are possible: single-shot (100 ns to 100,000 s), averaging (down to 10 ps resolution), and time-interval delay. The MRC counters also measure/perform: Period A, Ratio A/B, A by B (totalizes A input between 2 events on B), and Totalize (manually gated mode).

Both channels offer input signal conditioning controls: +/-slope, ± 2.5 Vdc trigger level, and AC/DC coupling. A SEPARATE/COMMON switch (to link internally input A to input B) and a 100-kHz low-pass filter for Channel A are included.

Time Interval Measurements

The 5316B lends itself to an interesting reflection. I have often wondered why digital counters have more than one signal inputs; this was the good opportunity to deepen this question. In general, two inputs are provided to make possible time interval measurement. The 5316B has furthermore a button (SEParate / COMmon A) that connects input A to input B, without requiring an external cable.



1



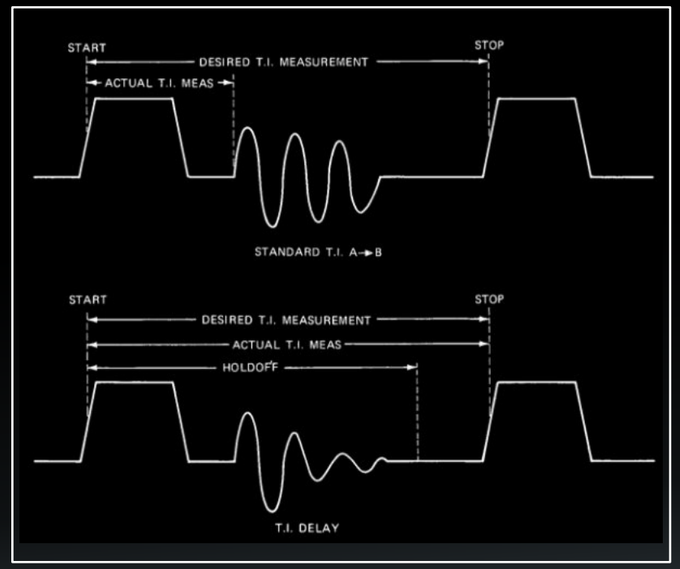
2



3

In the simplest case (T.I. A→B) one input is used to start time count and the other to stop it. But there are other options:

- **T.I. average mode** (T.I. AVG A→B) provides greater resolution; the GATE TIME control varies the number of events of time intervals averaged (approximately GATE TIME X REP RATE). The resolution of the measurement is improved by the √N, where N is the number of time intervals averaged.
- in **T.I. DELAY mode** front panel GATE TIME control inserts a holdoff (variable delay from 500 us to 30 ms) between the START (INPUT A) event and the enabling of the STOP (INPUT B) event. Potential STOP events are ignored during the specified delay. The amount of delay time may be continuously measured and displayed by simultaneously pressing the T.I. A--B, T.I. DELAY, and Blue Shift keys (see the picture).



Comparing With a Properly Plugged Oscilloscope

Why did I described rather in detail the time interval measurement? Because studying it we can better understand some friend of ours which we met talking about the Tektronix 7000-Series timer counter plug-ins: I am talking about the 7D14 and 7D15 counters. They, with the scope, give something that counters like the 5316B don't have, i.e., the capability to "see" what the triggers are doing. Imagine that you have to perform the measurement of the above picture. Understanding if the current holdoff value is too short or too long is not easy, also because the trigger signal on the panel is just the DC value.

In the case of a 7000 oscilloscope with a digital counter plug-in, you can see not only the input signal but also the trigger and the relationships between them. A whole other life!

Construction

The 5316B construction resembles many other instruments described in this book, with a single large board for most circuits. This approach, clearly, became possible only with the arrival of LSI integrated circuits.

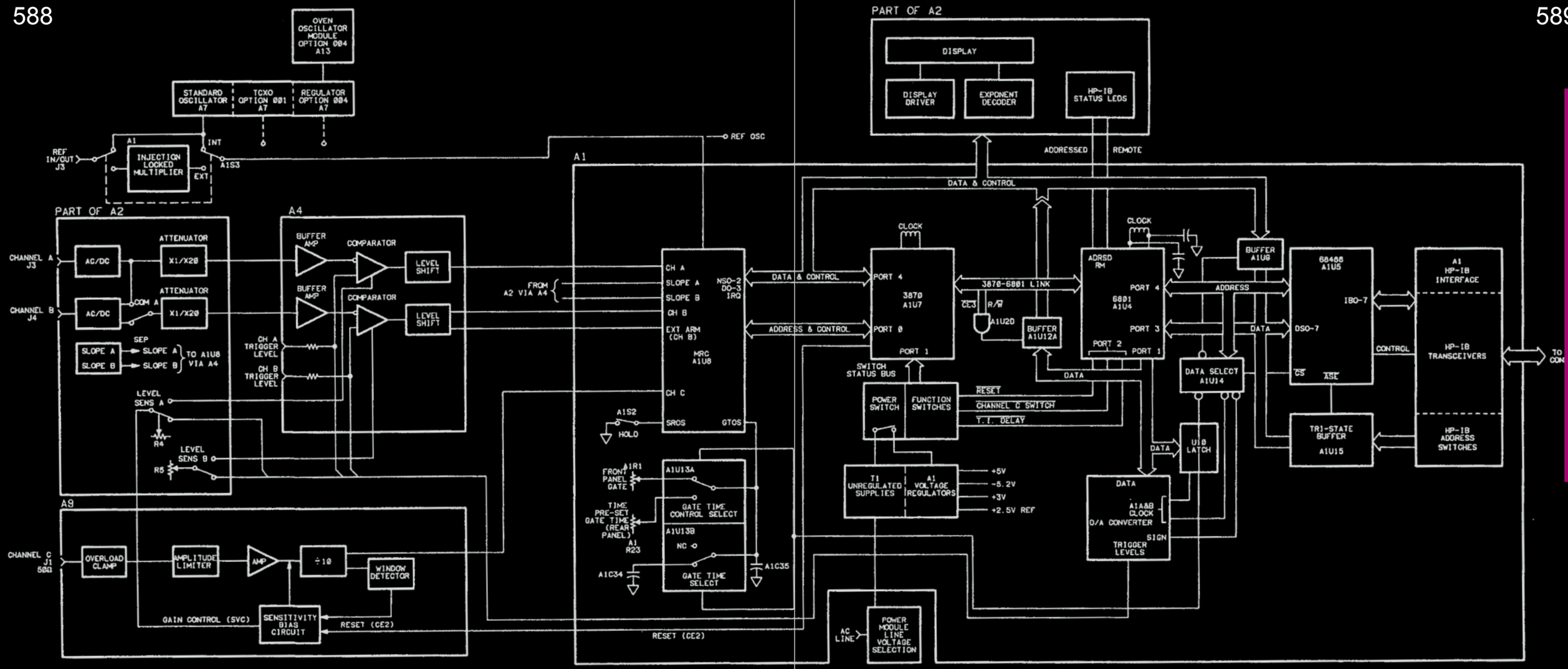
Note that the main board is just two-sided; today nobody would do without a multilayer board, at least for EMC issues. The assembly is very ordered and clean, a good technology piece.

Circuitry

On the next page you can see the block diagram, where you can observe that the HP 5316B utilizes five LSI circuits.

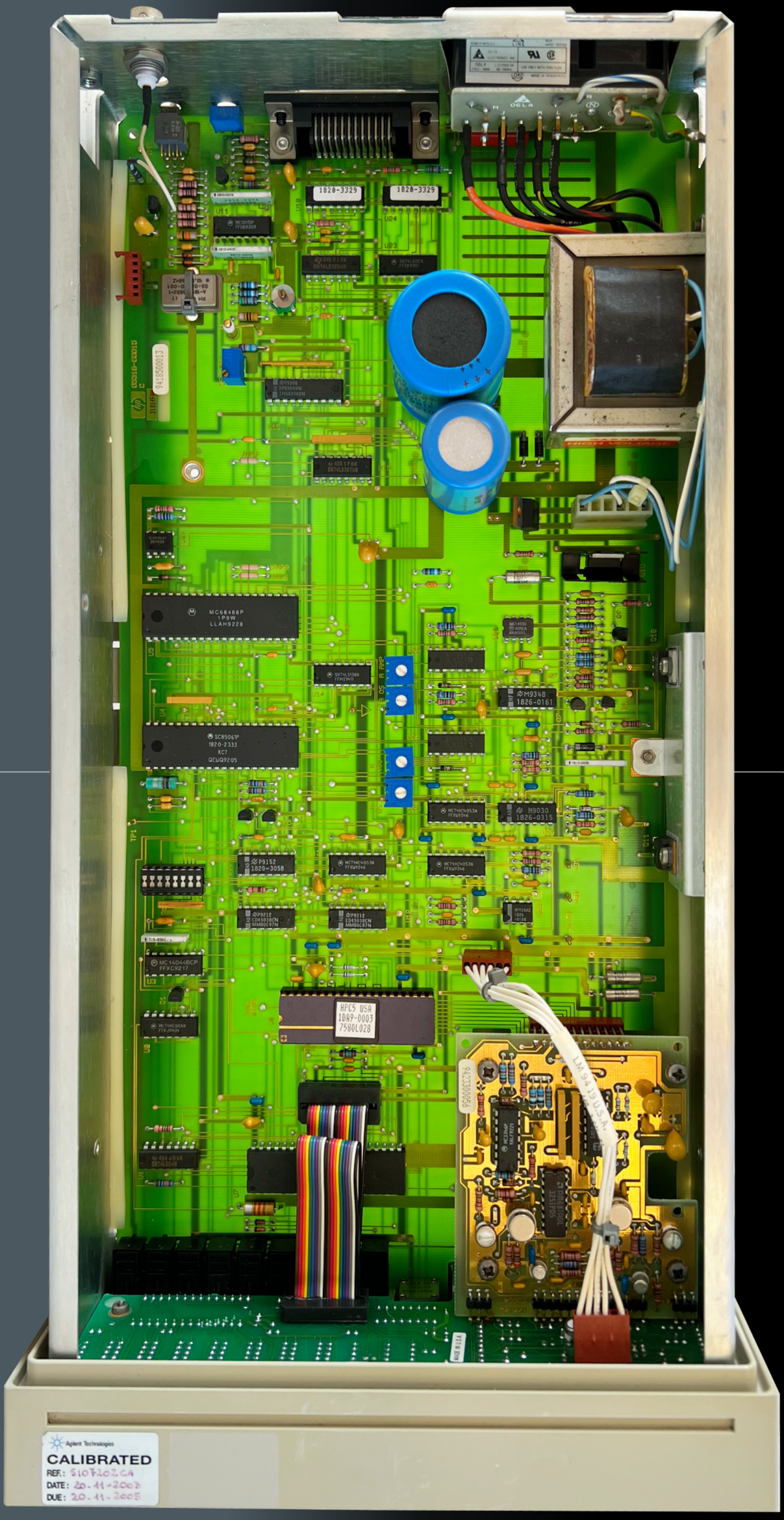
A Microprocessor (A1U7) controls the Multiple-Register-Counter (MRC A1U8) to form the basic counter system. A microprocessor (A1U4) controls the HP-IB Interface (A1U5) to handle all bus operations. (A1U4) exchanges…





…data with (A1U7). In addition, a Display Decoder/Driver (A2U1) formats that display data for the eight -7 segment LEDs. The A1U7 processor is, incredible, a Fairchild F8, the one that had an important part in my life (see “Reverse Polish Notation” in Tektronix 7000-Series book).

With today eyes I liked immediately the 5316B, as soon as I took it out of the box. It was like new and perfectly operating, still with the calibration seals from the last check, performed on November 11, 2003. Even today, within its limits, is perfectly usable and very practical.


1820-3329
1820-3329
MC68488P
1P9W
LLAH9228
SC85061P
1820-2333
KC7
GEWQ9205
M9348
1826-0161
M9030
1826-0315
P9152
1820-3058
MC14044BCP
FFXC9217
HPC5 USA
1DA9-0003
7580L028
Agilent Technologies
CALIBRATED
REF: 5107202CA
DATE: 20-11-2003
DUE: 20-11-2005



Section:

Counters

Subsection:

5335A Universal Counter

An advanced universal counter with built-in automatic measurement functions, math and statistics.



The 5335A was defined an Universal Counter, and aimed to bring more measurement power for the money than any other bench or systems universal counter available at the moment.

Even seen with today's eyes, it is a very interesting instrument, capable to perform several uncommon functions, such as mathematical operations and statistics.

1980

5335A Universal Counter

Family Feeling

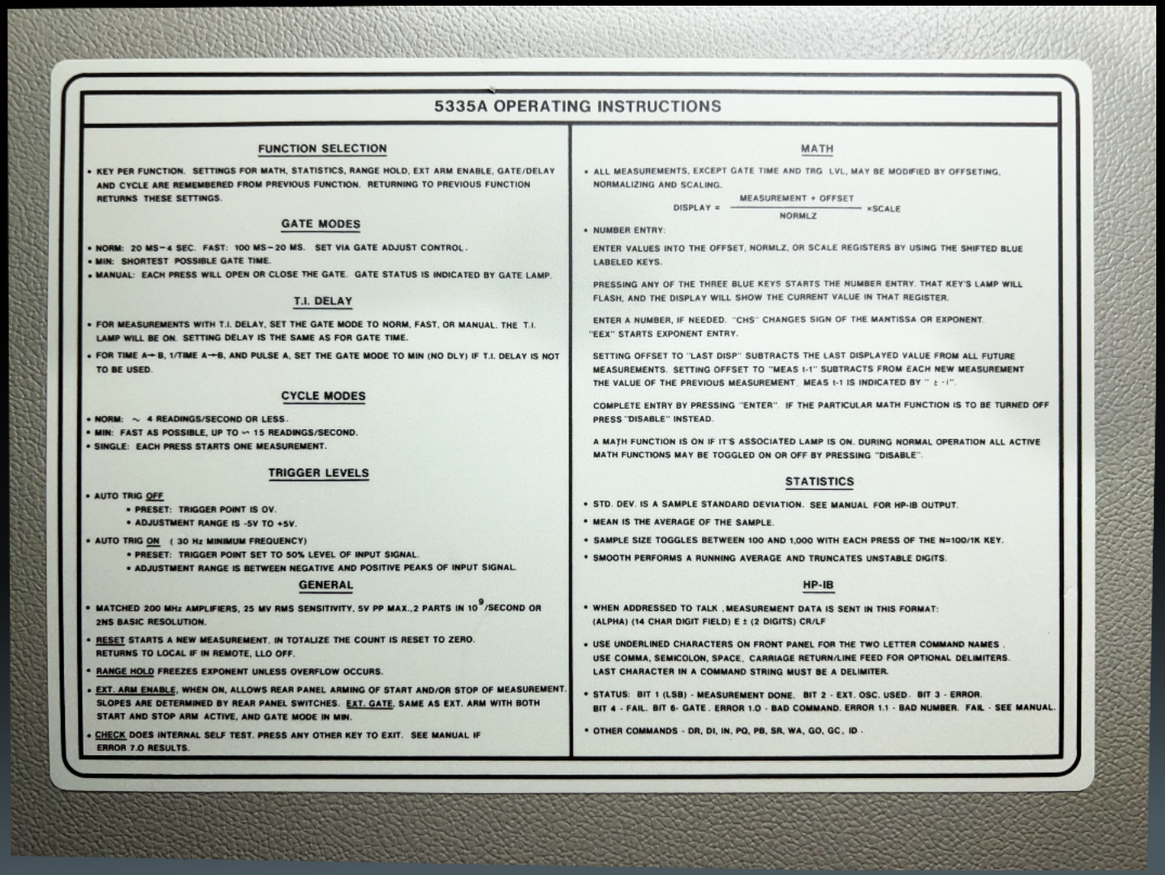
Comparing the 5335A to the 3325A Synthesizer/ Function Generator, their kinship is evident, or, as we say today, they have the same Family Feeling.

The 3325 had been introduced the year before (1979), but they show the same look and use common solutions, like a Motorola processor from the 6800 family, very accepted at the time, also on the personal microcomputer market.

I like very much these instruments, impossible dreams at their time. They are generally very well conceived and built, and, if you forgive them the age, are still perfectly usable.

In truth, I believe that having a knob or a key for almost every function is a great advantage. I must confess that I hate the ubiquitous touch screens, in my opinion far to be ergonomic as they pretend to be.





5335A OPERATING INSTRUCTIONS

FUNCTION SELECTION

- KEY PER FUNCTION. SETTINGS FOR MATH, STATISTICS, RANGE HOLD, EXT ARM ENABLE, GATE/DELAY AND CYCLE ARE REMEMBERED FROM PREVIOUS FUNCTION. RETURNING TO PREVIOUS FUNCTION RETURNS THESE SETTINGS.

GATE MODES

- NORM: 20 MS–4 SEC. FAST: 100 MS–20 MS. SET VIA GATE ADJUST CONTROL.
- MIN: SHORTEST POSSIBLE GATE TIME.
- MANUAL: EACH PRESS WILL OPEN OR CLOSE THE GATE. GATE STATUS IS INDICATED BY GATE LAMP.

T.I. DELAY

- FOR MEASUREMENTS WITH T.I. DELAY, SET THE GATE MODE TO NORM, FAST, OR MANUAL. THE T.I. LAMP WILL BE ON. SETTING DELAY IS THE SAME AS FOR GATE TIME.
- FOR TIME A→B, 1/TIME A→B, AND PULSE A, SET THE GATE MODE TO MIN (NO DLY) IF T.I. DELAY IS NOT TO BE USED.

CYCLE MODES

- NORM: ~ 4 READINGS/SECOND OR LESS.
- MIN: FAST AS POSSIBLE, UP TO ~ 15 READINGS/SECOND.
- SINGLE: EACH PRESS STARTS ONE MEASUREMENT.

TRIGGER LEVELS

- AUTO TRIG OFF
  - PRESET: TRIGGER POINT IS 0V.
  - ADJUSTMENT RANGE IS -5V TO +5V.
- AUTO TRIG ON (30 Hz MINIMUM FREQUENCY)
  - PRESET: TRIGGER POINT SET TO 50% LEVEL OF INPUT SIGNAL.
  - ADJUSTMENT RANGE IS BETWEEN NEGATIVE AND POSITIVE PEAKS OF INPUT SIGNAL.

GENERAL

- MATCHED 200 MHz AMPLIFIERS, 25 MV RMS SENSITIVITY, 5V PP MAX.,2 PARTS IN 10^9/SECOND OR 2NS BASIC RESOLUTION.
- RESET STARTS A NEW MEASUREMENT, IN TOTALIZE THE COUNT IS RESET TO ZERO. RETURNS TO LOCAL IF IN REMOTE, LLO OFF.
- RANGE HOLD FREEZES EXPONENT UNLESS OVERFLOW OCCURS.
- EXT. ARM ENABLE. WHEN ON, ALLOWS REAR PANEL ARMING OF START AND/OR STOP OF MEASUREMENT. SLOPES ARE DETERMINED BY REAR PANEL SWITCHES. EXT. GATE. SAME AS EXT. ARM WITH BOTH START AND STOP ARM ACTIVE, AND GATE MODE IN MIN.
- CHECK DOES INTERNAL SELF TEST. PRESS ANY OTHER KEY TO EXIT. SEE MANUAL IF ERROR 7.0 RESULTS.

MATH

- ALL MEASUREMENTS, EXCEPT GATE TIME AND TRG. LVL, MAY BE MODIFIED BY OFFSETING, NORMALIZING AND SCALING.

$$\text{DISPLAY} = \frac{\text{MEASUREMENT} + \text{OFFSET}}{\text{NORMLZ}} \times \text{SCALE}$$

- NUMBER ENTRY:

ENTER VALUES INTO THE OFFSET, NORMLZ, OR SCALE REGISTERS BY USING THE SHIFTED BLUE LABELED KEYS.

PRESSING ANY OF THE THREE BLUE KEYS STARTS THE NUMBER ENTRY. THAT KEY'S LAMP WILL FLASH, AND THE DISPLAY WILL SHOW THE CURRENT VALUE IN THAT REGISTER.

ENTER A NUMBER, IF NEEDED. "CHS" CHANGES SIGN OF THE MANTISSA OR EXPONENT. "EEX" STARTS EXPONENT ENTRY.

SETTING OFFSET TO "LAST DISP" SUBTRACTS THE LAST DISPLAYED VALUE FROM ALL FUTURE MEASUREMENTS. SETTING OFFSET TO "MEAS t-1" SUBTRACTS FROM EACH NEW MEASUREMENT THE VALUE OF THE PREVIOUS MEASUREMENT. MEAS t-1 IS INDICATED BY " Σ -1".

COMPLETE ENTRY BY PRESSING "ENTER". IF THE PARTICULAR MATH FUNCTION IS TO BE TURNED OFF PRESS "DISABLE" INSTEAD.

A MATH FUNCTION IS ON IF IT'S ASSOCIATED LAMP IS ON. DURING NORMAL OPERATION ALL ACTIVE MATH FUNCTIONS MAY BE TOGGLED ON OR OFF BY PRESSING "DISABLE".

STATISTICS

- STD. DEV. IS A SAMPLE STANDARD DEVIATION. SEE MANUAL FOR HP-IB OUTPUT.
- MEAN IS THE AVERAGE OF THE SAMPLE.
- SAMPLE SIZE TOGGLES BETWEEN 100 AND 1,000 WITH EACH PRESS OF THE N=100/1K KEY.
- SMOOTH PERFORMS A RUNNING AVERAGE AND TRUNCATES UNSTABLE DIGITS.

HP-IB

- WHEN ADDRESSED TO TALK, MEASUREMENT DATA IS SENT IN THIS FORMAT: (ALPHA) (14 CHAR DIGIT FIELD) E ± (2 DIGITS) CR/LF
- USE UNDERLINED CHARACTERS ON FRONT PANEL FOR THE TWO LETTER COMMAND NAMES. USE COMMA, SEMICOLON, SPACE, CARRIAGE RETURN/LINE FEED FOR OPTIONAL DELIMITERS. LAST CHARACTER IN A COMMAND STRING MUST BE A DELIMITER.
- STATUS: BIT 1 (LSB) - MEASUREMENT DONE. BIT 2 - EXT. OSC. USED. BIT 3 - ERROR. BIT 4 - FAIL. BIT 6- GATE. ERROR 1.0 - BAD COMMAND. ERROR 1.1 - BAD NUMBER. FAIL - SEE MANUAL.
- OTHER COMMANDS - DR, DI, IN, PQ, PB, SR, WA, GO, GC, ID.

Power for the Money

An Innovating Counter

In the early eighties, most electronics was by now going digital, and many digital circuits parameters like pulse width, duty cycle, and phase had become significant. A conventional counter could not be used to measure these parameters, or at least multiple setups were needed, accompanied by manual calculation.

The 5335A offered new functions, or at least functions I was not used to see in a digital counter, in addition to the HP-IB extended programmability. As we explore further below, we could synthesize the novelties in two groups (which we have seen and are going to see also in oscilloscopes):

- math and statistics;
- automatic measurements.

In addition to these special functions, the 5335A had also good general performances, with 200 MHz range and 12-digit display, and offered also the possibility to add very interesting options.

Prices and Options

The price of the 3325A in 1980 was of $2,950, equivalent to $11,243.98 in 2024. But you had available very interesting options (in parentheses the equivalent today):

- Opt 010: Oven Oscillator: $650 (2,477);
- Opt 020: Digital Voltmeter (DVM) with auto-ranging, auto-polarity, ±10, ±100, ±1000V ranges, 100 μV to 100 mV sensitivity (depending on range), up to 4 digits: $275 (1,048);
- Opt 030: C Channel, with 150 MHz to 1.3 GHz with C/A capability: $450 (1,715).

Interesting the voltmeter; it was completely independent from the counter, just like the Tektronix 7D13. Digital voltmeters were a novelty and the possibility to share the display was evidently considered important. Surprising that the most expensive was the oven; I would have thought it was the C Channel.

Would I Have Bought It?

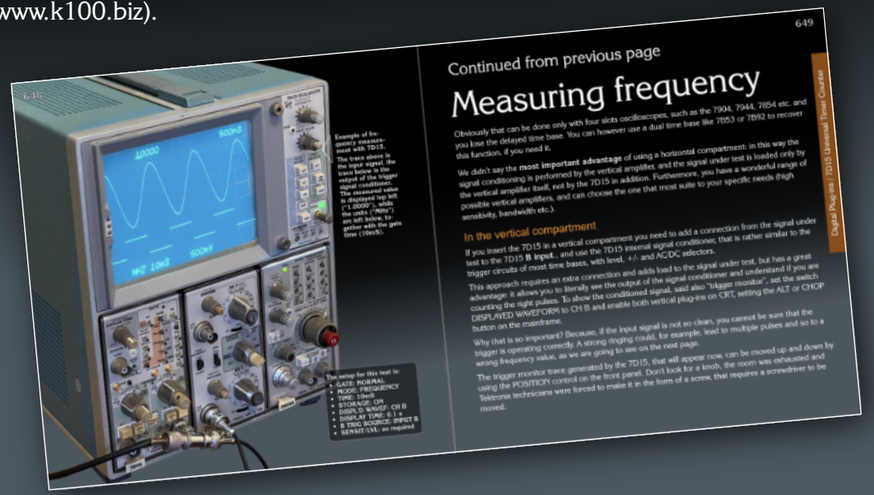
I asked myself if, in 1980, I wouldn't prefer to buy a Tektronix 7603 oscilloscope with a 7D15 225 MHz Universal Counter/Timer instead of a HP 5335A. The answer is "it depends".

A complete Tektronix configuration would cost:

- 7603 mainframe: $2,260
- 7D15 225 MHz Universal Counter/Timer: $2,250
- 7B53A Dual Time base: $1,100
- 7A18 Dual Trace Amplifier: $915

The total is $6,525. Compared to $2,950 of the 5335A, it is more than twice. Yes, you get also a good oscilloscope, but you have not the GP-IB programmability, which is no small thing, and less ergonomics. The difference of technology from the "new" HP instrument line and the old 7000 Series is starting to be felt.

You can form your own irrelevant (like mine) opinion about that reading my free e-Book "Tektronix, the 7000 Series", where the 7D15 is thoroughly described and which you can download from my web page (www.k100.biz).



Math & Statistics

Math

Math capabilities of Normalize, Offset, Scale, Last Display Deviation, and Measurement t-1 Deviation are included as standard, as are Statistical measurements of Mean (Average), Standard Deviation, and Smooth. These features carried the usefulness of the 5335A into the industrial, scientific and communications areas.

Any measurement result could be mathematically modified for display in more convenient units. Offset, Normalize, and Scale could be used independently or together as follows:

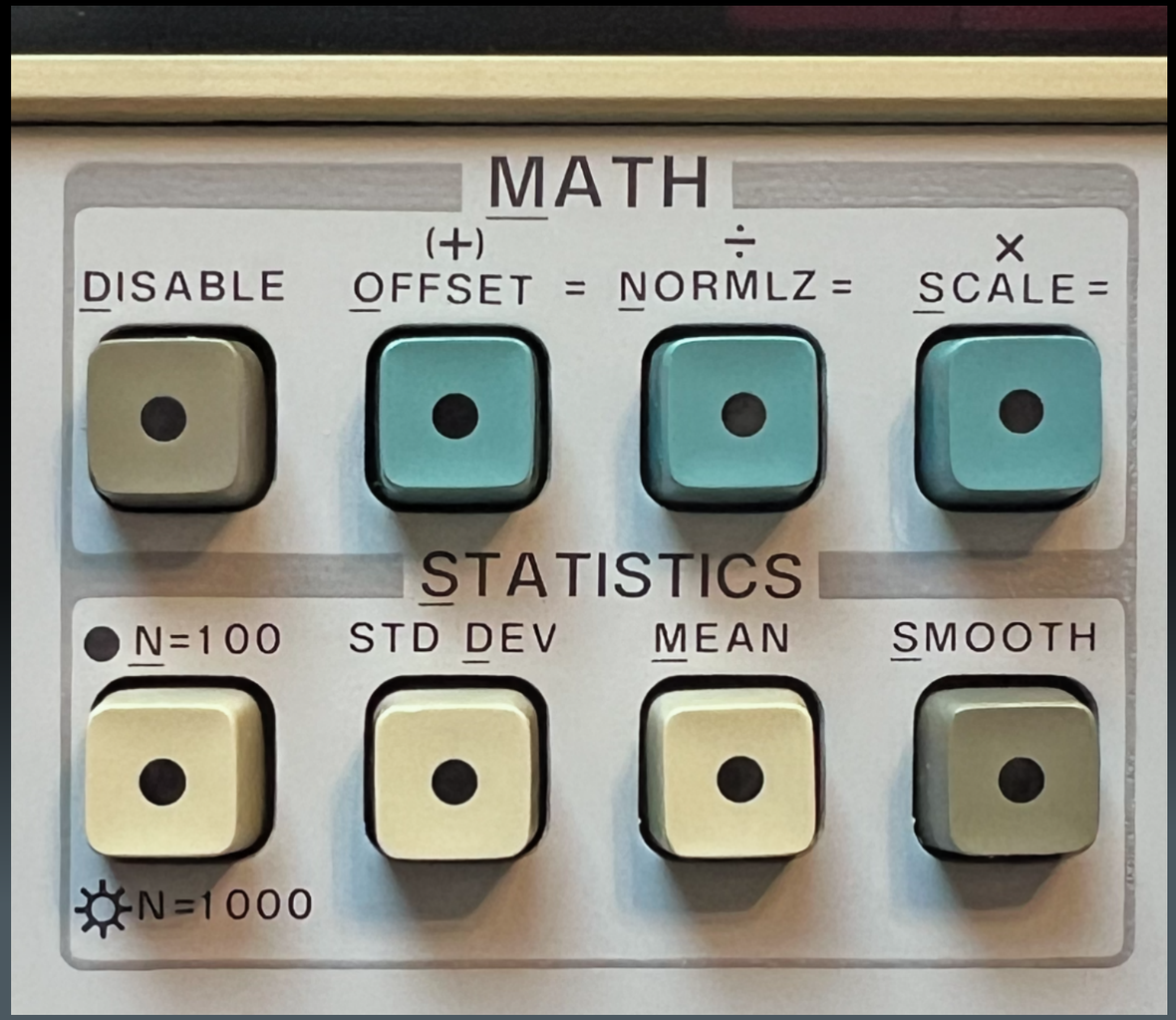
- Display = (Measurement + Offset) x Scale / Normalize.

Numbers are entered via the blue labeled keys. DISABLE key will toggle off and on all selectable math keys. Last display key causes the value of the previous display to Offset, Normalize, or Scale all subsequent measurements. Measurement t-1 key causes each new measurement to be subtracted from each new immediately preceding measurement.

Statistics

In addition to math, the 5335A allowed also to perform statistical functions on data sets composed by 100 to 1000 samples. The functions are:

- Std. deviation: displays a standard deviation of selected sample size;
- Mean: displays the mean estimate of selected sample size;
- Smooth: performs a running weighted average and truncates unstable least significant digits from the display.





Telefunken E863

The 1969 Telefunken **E 863 KW/2** was a general-purpose, highly stable shortwave receiver for telegraphy and telephony, including SSB operation, as well as a search and monitoring receiver.

It was probably one of the first fully transistorized professional radio devices and was designed in the second half of the sixties by the rebuilt German industry, destroyed after the WW-II.

It covered the shortwave range from **1.5 to 30 MHz** in just 4 sub-ranges with one-button tuning.

It was very innovative, thanks to the PLL frequency control and the built-in frequency counter using Nixie tubes, with a resolution of 100 Hz.

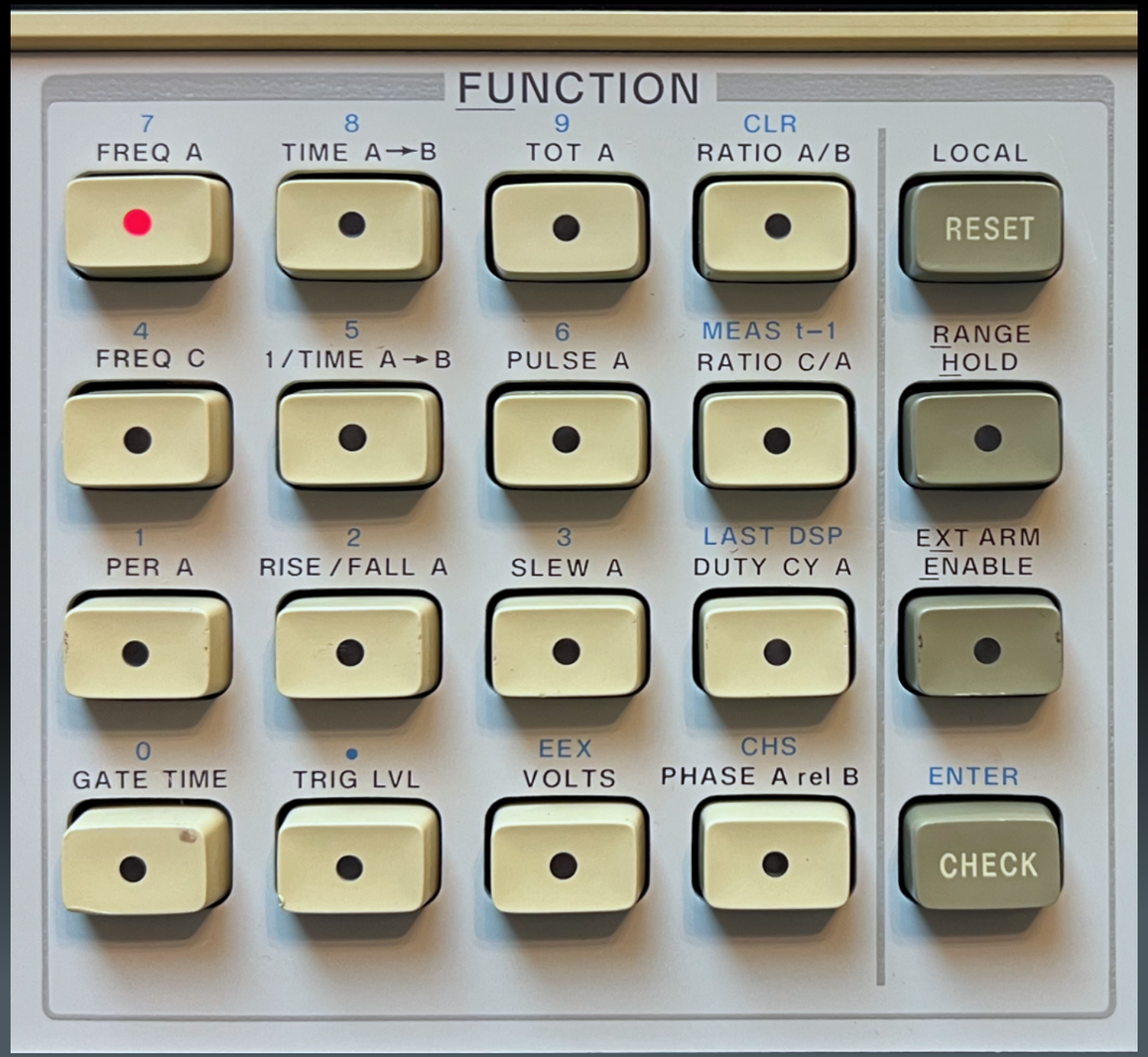
The E863 has, on the rear panel, a BNC connector with the signal from the local oscillator. Being a single-conversion receiver, it simply oscillates 525 kHz above the received frequency, so it is a wonderful case study for our purposes.

Fact Checking



Does it Really Work?

I wanted to test the math functions by realizing a digital display for an analog radio receiver. In a single conversion superheterodyne receiver, the local oscillator does work at the received frequency, but has an offset, positive or negative, of the intermediate frequency value. The E863 has an IF value of 525 kHz and the oscillator runs at the received frequency +525 kHz. So I used the OFFSET key setting a value of -525000. As you can see in the photos, it works perfectly (and gives more digits of the real frequency than the receiver's built-in).



Automatic Measurements

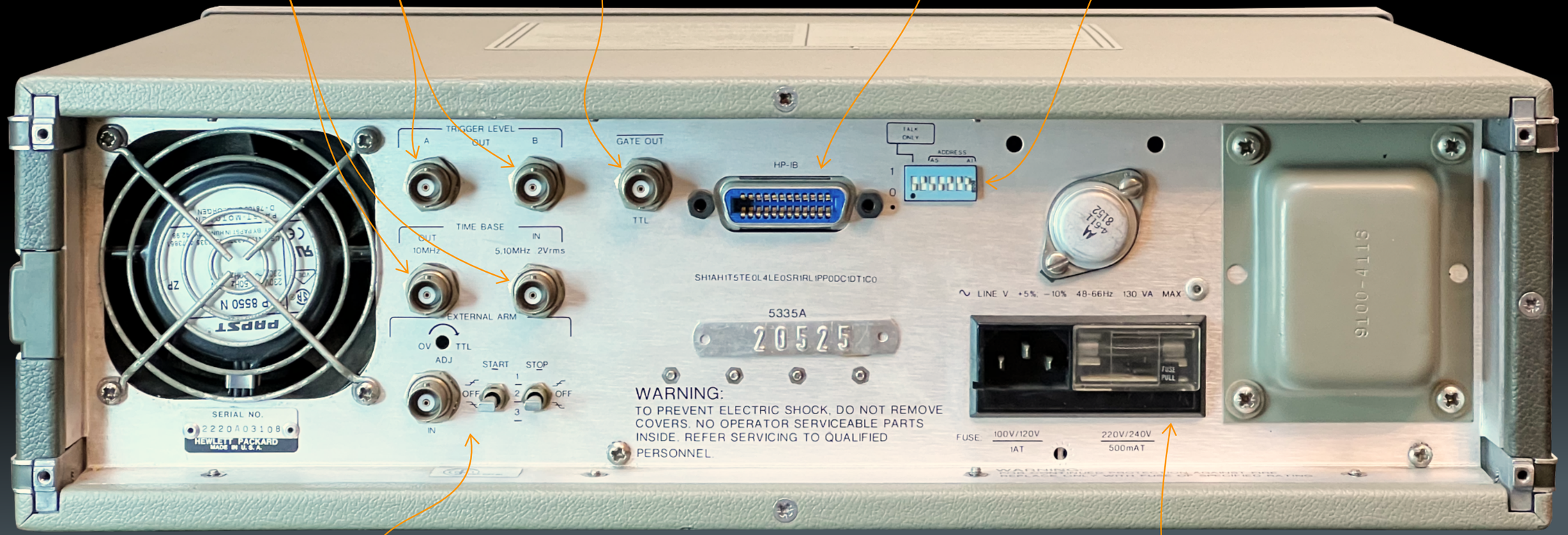
Automatic Measurements

Manual/Automatic Triggering circuits allowed to either set the trigger levels yourself, or have the 5335A set them. Using this capability to the fullest carried the 5335A beyond the usual universal counter measurements of Frequency, Period, Time Interval, Ratio and Totalize to include measurements such as

- Pulse Width;
- Rise and Fall Time (10% to 90%);
- Slew Rate;
- Duty Cycle;
- Phase A Relative to B;
- Inverse Time Interval (velocity).

All done automatically at the push of a button. Also both A and B channel trigger levels and gate time could be measured and displayed on the standard 5335A.

B-Side



Timebase IN and OUT

Trigger Level A & B Out

Gate Out

HP-IB

HP-IB Address Selector Switch

External Arm Input Connector and Slope Selectors

AIO Power Module

Block Diagram

Two Main Blocks

The block diagram from HP Journal 9/1980 reveals a counter far from the traditional vein of the time. Two main blocks were the centers of activity:

- the Multiple-Register Counter (MRC) LSI integrated circuit, which performs all the basic counter functions. We already met this "counter-on-a-chip" talking about the 5316x and in the introduction. It was first used in the 5315 Universal Counter.
- the 6800-microprocessor system.

All of the other blocks act as support.

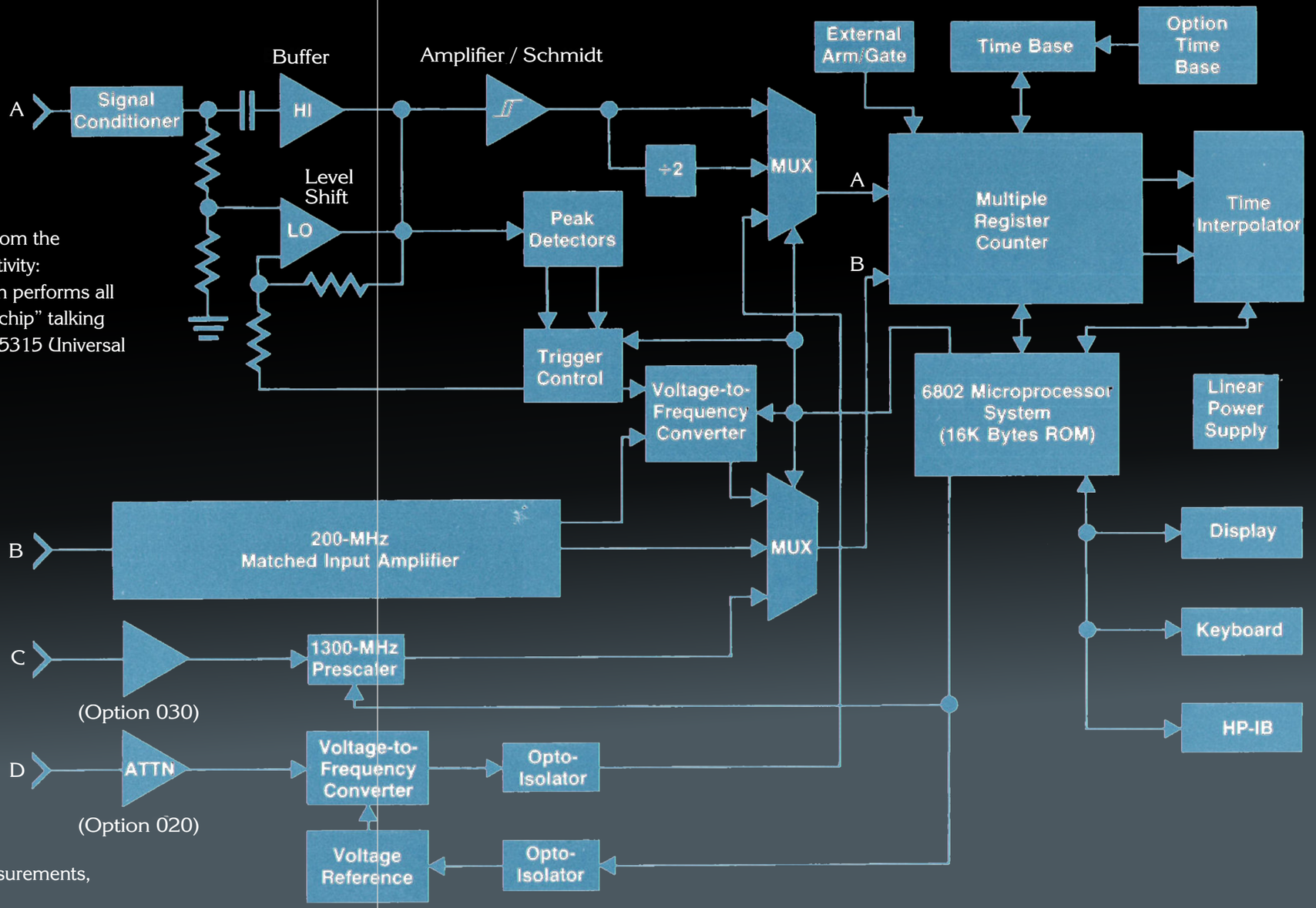
Unprecedented Flexibility

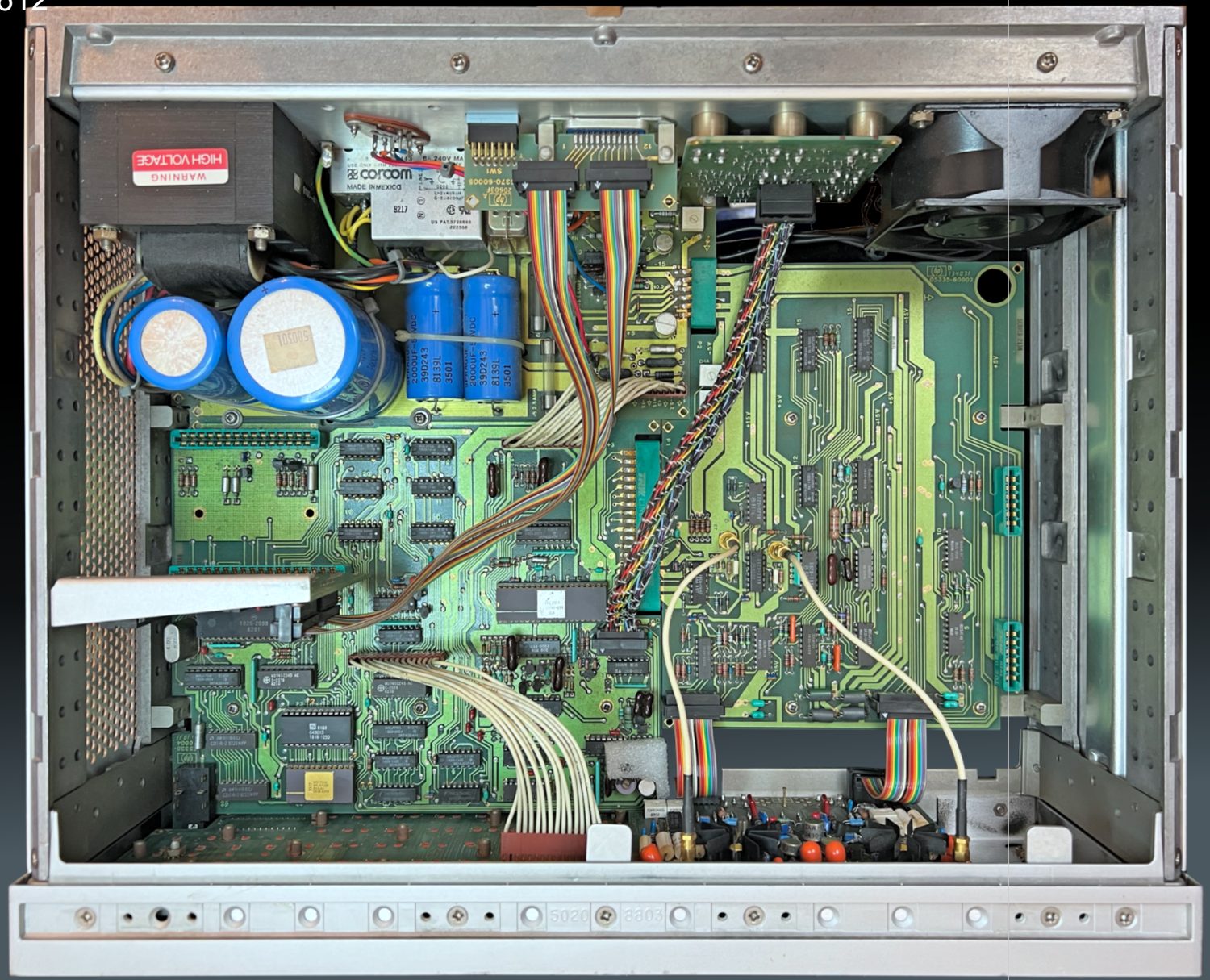
The microprocessor centralized architecture gave the design team a tremendous flexibility, compared to the old discrete-components approach, and made possible unusual capabilities.

For instance, function selection was directly controlled by the processor, and only indirectly controlled by the keyboard. This means that the processor had the freedom to combine several measurements into one to arrive at more complex measurements.

Among the innovative sections of the counter were the trigger controls and the interpolators. These provided a number of features that made the counter easier to use by simplifying trigger setups and increasing resolution.

The block diagram also shows the use of matched A and B input amplifiers. This is important in assuring accurate time interval measurements, particularly since time could be resolved down to 100ps.





LSI Counter

As anticipated, the gating, synchronizing and counting circuitry needed to perform the measurements was all within the mythical MRC.

The MRC was a dedicated processor-compatible peripheral, designed to perform all of the high-speed functions required in a universal counter. Built with emitter function logic and I^2L, over 4000 active elements provide the logic to control, count, and give the status of a wide variety of measurements. The MRC first appeared in the 5315A Universal Counter, where much of its power was used, but not all. In the 5335A the full power of the MRC is used to maximum advantage.

For instance, the interpolation pulses required for high resolution were generated within the MRC. The same circuitry also generated the calibration signals. In addition, there was a built-in option to insert a fixed delay into the counter's stop channel, making possible the measuring of time intervals down to 0 ns, single shot. The delay was automatically taken into account during a special calibration procedure, yielding accurate time intervals in spite of time and temperature variations.

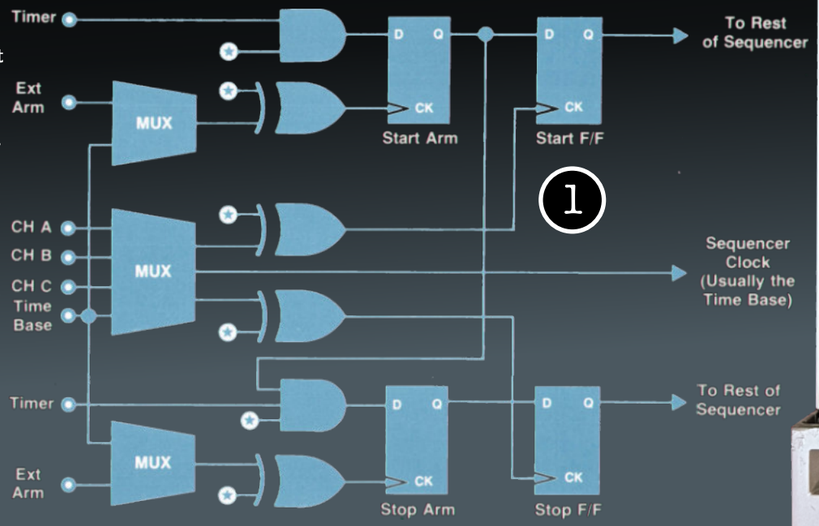
An elaborate synchronized gating circuit assured that the measurement started and stopped exactly when required. Provisions had been made for arming the measurement in a number of different ways. Arming could be done by a TTL signal, an HP-IB command, automatically by the counter, or manually. A look at the simplified synchronizer circuit (❶ on the next page), shows that a number of conditions had to be met for the gate to open and close. The MRC's control register determined which condition had to be met for any particular measurement. For example, the opening of the gate could be made conditional on a signal from channel A, channel B, or channel C, as well as on a number of other signals. Such flexibility means that a function like TIME INTERVAL B TO A was just as easy to do as TIME INTERVAL A TO B. The 5335A provided both of these functions at a cost of just a few bytes of program memory.

As mentioned, the ability to arm the measurement based on an external TTL signal was built in. Traditionally, this ability had been fairly restrictive, sometimes being limited to the arming of just the starting point. When the stopping point could also be armed, it was usually for time interval measurements only. With the MRC, none of these restrictions apply.

The ability to arm the start and the stop of almost any measurement was an inherent ability of the MRC. There are over a dozen arming combinations. Arming of the start and stop of a measurement could be done individually or together, and from either slope of the arming signal. Arming and gating could be internal or external. Such precise control over when the measurement was made made it much easier to make such measurements as frequency shift keying (FSK) and pulse repetition frequency (PRF).

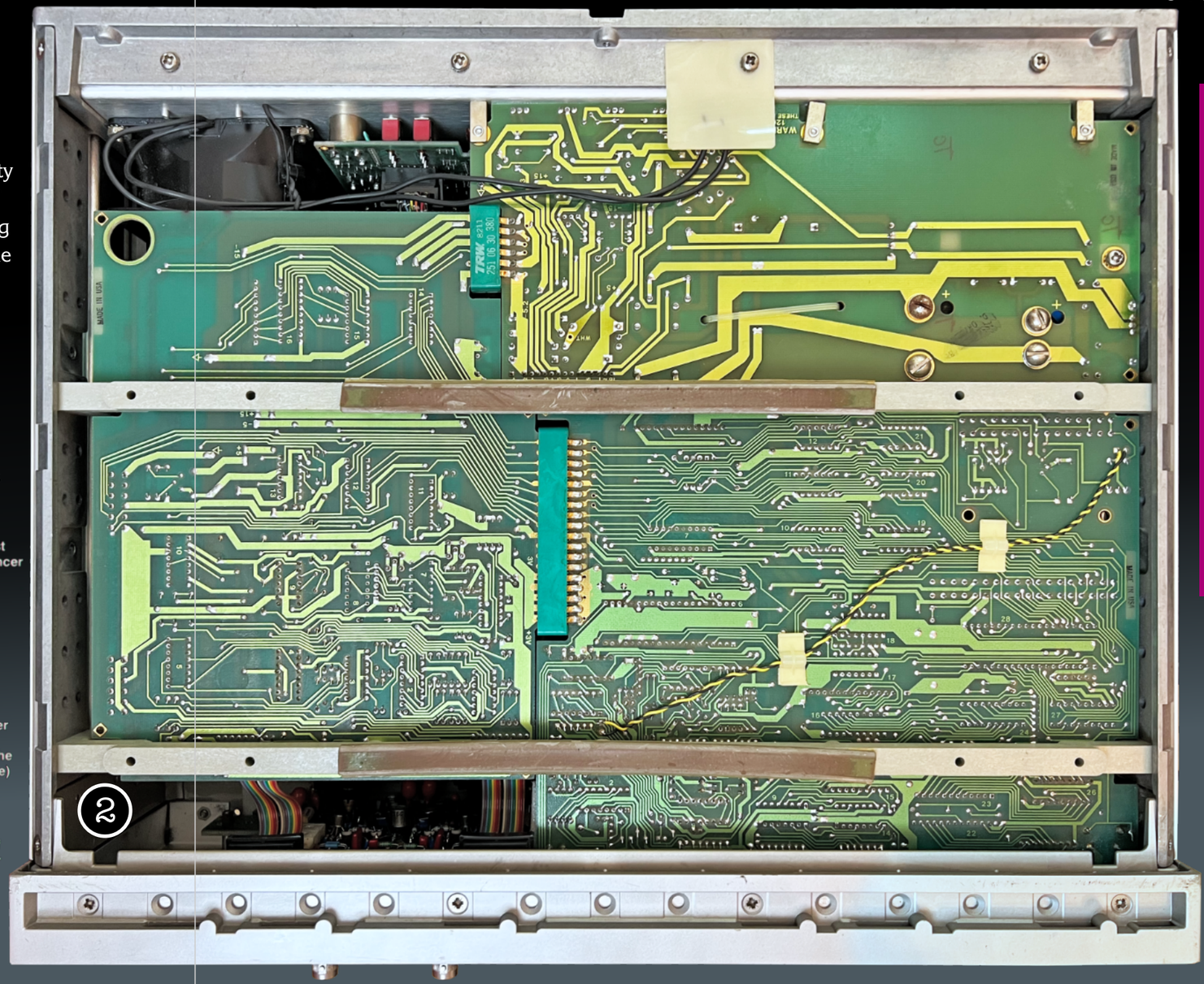
Another feature of the MRC let its internal eight-decade count chains be expanded to any number of decades with the help of a processor. This feature was used to create a pair of count chains, each 20 decades long. With a 100-MHz signal, this chain would take more than 30,000 years to overflow.

Consequently, the 5335A had no overflow annunciator, so gate times could be as short as 0 ns or as long as years.



❶ An elaborate synchronized gating circuit assures that 5335A measurements start and stop precisely as required. This is a simplified portion of the gate sequencer. The gate's start can be conditional on several signals. Exclusive-or gates select the signal's slope. The *symbols represent control signals from the processor.

❷ 5335A's bottom view. The boards subdivision is clear.



Split-Band Amplifiers

Good input amplifiers are essential for any measurement instrument, and a lot of attention was given to their design. Among the new requirements set by the digital revolution, there was the need to manage, without attenuators, a wider assortment of signals, such as TTL levels, and that required the possibility to set the trigger level in a range of ±5 volts, about twice the range of previous counters.

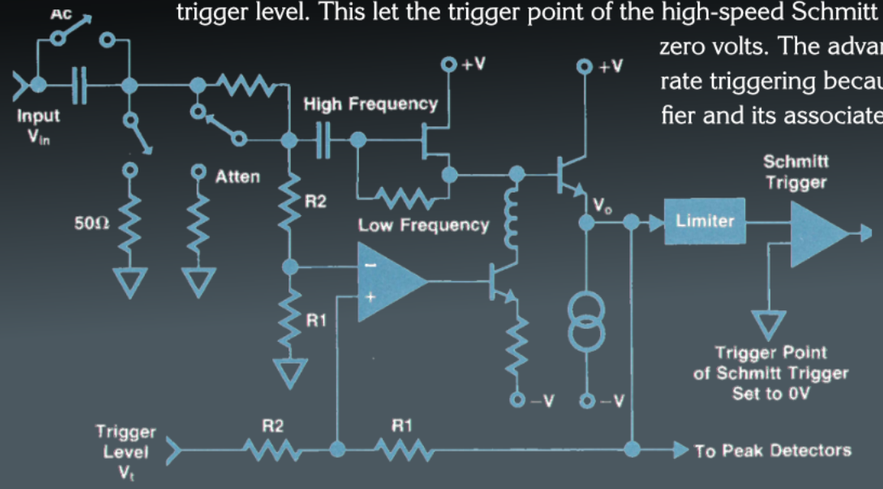
This wide range was accomplished by using a Split-Band Amplifier scheme, defined as "well-known", but unknown, like many other things, to me, except perhaps when talking of hi-fi speaker systems.

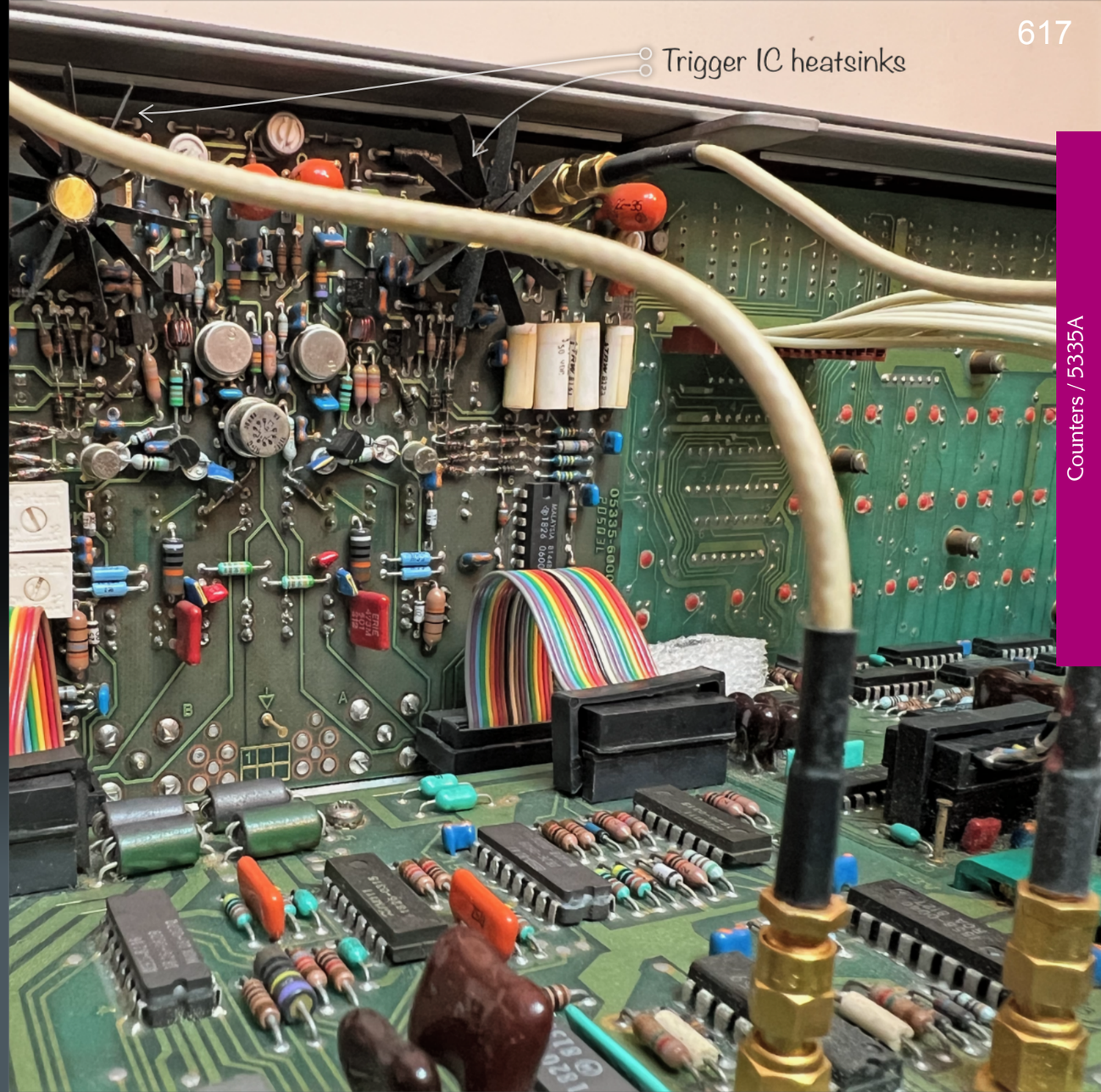
I learnt that such an amplifier has a high-frequency, AC coupled FET buffer path in parallel with a low-frequency, DC coupled, operational amplifier path. The 5335A crossover, i.e. the transition from the low to high frequency sections was at around 30 kHz, and:

- the high-frequency path gave excellent 25-mV sensitivity to 200 MHz;
- the low-frequency path gave precise control over DC offsets. By changing the bias to the operational amplifier the entire signal can be raised or lowered.

The FET buffer had a gain of about 0.95 and is matched by the low-frequency path with resistors R1 and R2. The overall transfer function of the buffer was V0 = (Vin- Vt) R1/R2

Unlike traditional counters, which move the trigger to the signal, this counter moved the signal to the trigger level. This let the trigger point of the high-speed Schmitt trigger be a constant zero volts. The advantage was more accurate triggering because the Schmitt amplifier and its associated circuitry were always biased at a fixed point. Also, there were no difficult common-mode requirements on the Schmitt amplifier, thus making the ±5 volt trigger range practical.



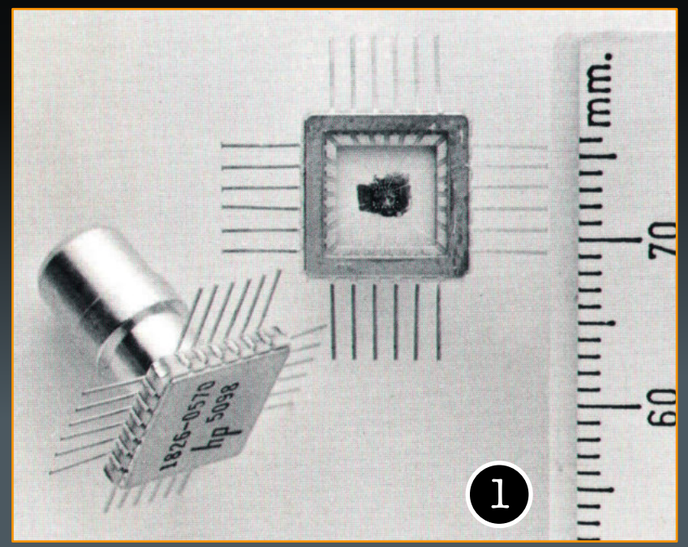


New Trigger, New Chips

HP intended that one of the more spectacular features of the counter could be its ability to set the trigger levels automatically, with three modes of automatic triggering.

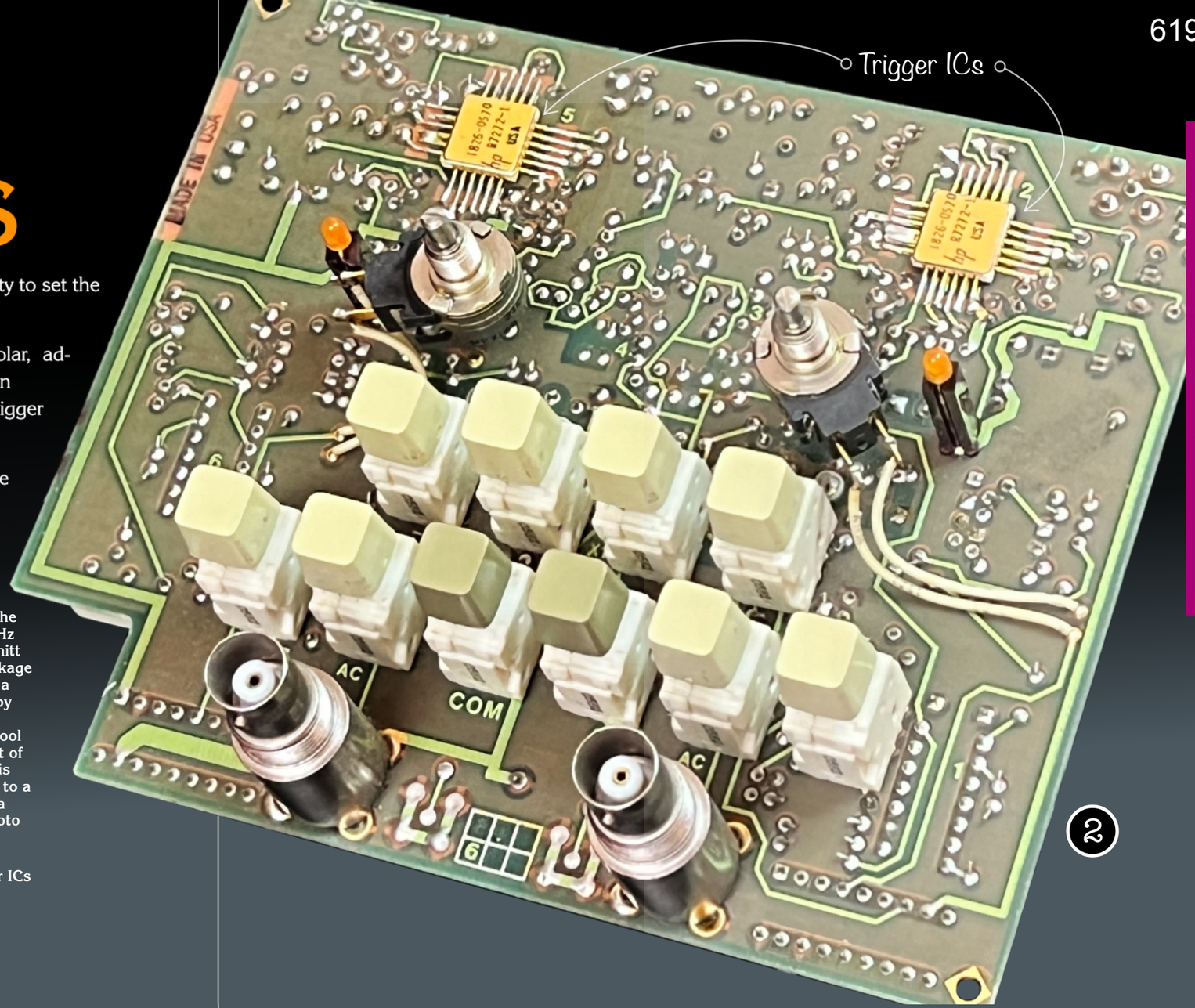
For this reason, they invested into the Schmitt trigger, with a special design 5-GHz bipolar, adjustable-hysteresis, Schmitt trigger integrated circuit, capable of operating at more than 500 MHz (❶). Built into the design were connections for slope select and three-state trigger lamps.

The circuit consisted of three main sections: an amplifier, a Schmitt trigger, and a pulse stretcher for the trigger lamps.



❶ Special packaging aids the performance of the 500-MHz adjustable-hysteresis Schmitt trigger. The flat 24-pin package permits shorter leads than a dual in-line package, thereby aiding high-frequency operation. To keep the IC cool in spite of the large amount of power it dissipates, the IC is bonded to a plate attached to a stud, which is attached to a heat sink (shown in the photo on the previous page).

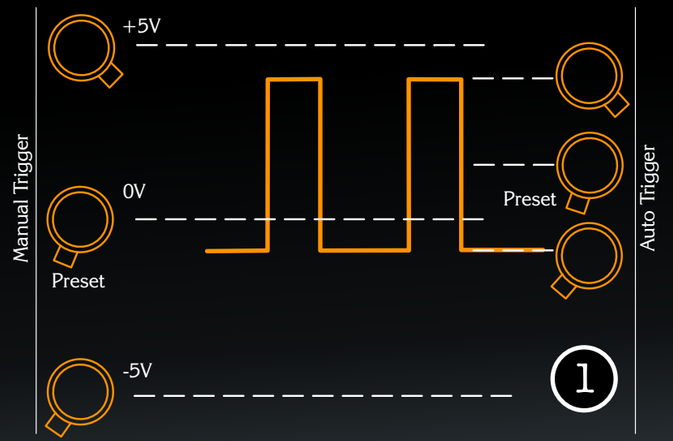
❷ The A3 Amplifier Buffer Board. Note the two trigger ICs in the higher part.



The amplifier had three Gilbert current gain cells that are used for wide bandwidth. The geometry of each transistor was tailored to match the expected current loads. To do this, extensive computer-aided design was employed.

To adjust the hysteresis, the bias of the amplifier was changed to vary its gain. Hysteresis windows of nominally 20 to 100 mV could be realized. The trigger threshold could also be adjusted. This adjustment is used to compensate for any offsets the rest of the front end may have.

The extra bandwidth and adjustment flexibility meant a more consistent trigger circuit and thus more accurate measurements.



❶ Redrawing from scratch this picture from the HP Journal 9/1980, I finally understood the 5335A's trigger controls.

❷ The TRIG LVL key shows the trigger levels for both triggers. Having two triggers is useful for the various possible gate functions. They can be used also internally, i.e., with no signal connected to the front panel. For example, if you press the RISE/FALL A button, the input waveform rise time is displayed (select the falling edge for the fall time). This is performed setting A trigger to 10% of the input signal and B to 90%. The counter starts with A and stops with B, measuring so the rise (fall) time).



Automatic Triggering

The 5335A trigger(s), like in an oscilloscope, had two modes: MANUAL or AUTOMATIC, selectable by mean of a button. In both cases, a knob allowed to set the trigger level.

- Automatic Triggering: when the knob is set to PRESET (picture ❶) the trigger level is automatically set to 50% of the input. For many applications this is all the user needs. Moving the knob from the PRESET position, you can choose the trigger level between minimum and maximum of the input signal. The counter continuously tracks it, adjusting the level as needed.
- Manual Triggering: the knob allows to set the trigger level between -5V and +5V; when on PRESET, trigger level is set to zero.

A third mode set the trigger levels to the 10% and 90% points of the signal. This was used for automatically making RISE/FALL and SLEW RATE measurements. Since these measurements involved both the A and B channels, the COMMON A mode was automatically invoked.

Automatic trigger level adjustment was based on knowing the peak values of the input. Once these are known, a simple voltage divider or potentiometer could be used to get the 10%, 50%, and 90% levels.

Trigger Monitoring

For monitoring the trigger levels once they were set, the counter provided three choices:

- three-state lights, first pioneered by the 5328A Counter, became standard on a variety of HP counters. These gave an instant indication of the status of the signal relative to the trigger levels. When the level is within the input, i.e. the counter is triggering, the lamp flashes, but a steady on or off lamp indicates either improper triggering or lack of signal;
- built-in digital voltmeter - To measure the trigger level in volts, a built-in digital voltmeter (DVM) simultaneously displayed both the A and B values at the press of the TRIG LVL key (picture ❷). The cost of including this DVM had been considered very small because of synergism with the rest of the counter. An inexpensive monolithic voltage-to-frequency converter and an analog switch were all that was needed. The power supply, voltage reference, control and counting circuits already existed.
- oscilloscope - The third choice of monitoring the levels was on an oscilloscope, using two rear-panel outputs. This method could be particularly useful if unusually shaped signals were being measured, since the trigger levels can be viewed along with the input signal.

HP-IB Programmability

Yet Another HP-IB Instrument

Like many other instruments we have dealt with, the 5335A was equipped and fully compatible with the Hewlett-Packard Interface Bus (HP-IB), created by Hewlett-Packard and then implemented as IEEE Std. 488-1978, "Standard Digital Interface for Programmable Instrumentation". We describe it more in detail in the dedicated section of this book.

The HP-IB capability was installed as standard equipment, and allowed the counter to respond to remote control instructions and output measurement results via the HP-IB. Almost every control on the 5335A could be programmed via the HP-IB. Programming was accomplished by addressing the counter as a listener and sending it device commands.

At the simplest level, the 5335A could output data to other devices such as the 5150A Thermal Printer or the 59303A Digital-to-Analog Converter.

However, in the eighties, sophisticated systems were going to become more and more frequently; in them, a controller, typically a computer, could remotely program the 5335A to perform a specific type of measurement, trigger the measurement, and read the results.

Putting it to Work

The 5335A manual is very well written, and includes examples for the 9800-Series computer, but, above all, for my beloved HP-85. What a beautiful opportunity to switch it on!

In the photo: the HP-IB interface board has a dedicated controller, the HP 1820-2219, which can be replaced by an MC68488 GPIB controller. Also the main processor can be seen, the HP 1820-2099, really a Motorola 6802.

Remotely Controlling the 5335A with the HP-85





To do this, I took the first example from the manual, named “Typical Measurement Format”, which shows how the controller can be used to display a measurement once every 5 seconds. This is the HP-85 listing:

```
10 DIM A$[21]
20 OUTPUT 703 ;"in"
30 ENTER 703 ; A$
40 DISP A$
50 WAIT 5000
60 GOTO 30
70 END
```

Another user convenience is seen every time the instrument is turned on. The HP-IB address is briefly displayed so that it can be verified by the operator.

After a measurement is accepted in step 2, the HP-IBs RFD (Ready For Data) line is held false until another read instruction is executed. This means that during the wait statement in step 4, the RFD line is false. The 5335A will check the RFD line whenever it is addressed to talk to make sure that the listening device is ready for data. If it finds RFD false and the wait mode is off, the counter will skip trying to output the data and start a new measurement.

In this example the 5335A will continue to make measurements without sending data until five seconds have passed. After five seconds, the next measurement that comes is sent. Note that this check of the RFD line is done for the first character of a measurement data string only. Subsequent characters are sent normally. Incredibly, it worked the first time, as you can see in the photo.

High Quality Design & Components

The 5335A was a son of the true, good, old Hewlett-Packard, queen of technology and quality, which taught us to love its instruments.

Electromagnetic compatibility was already considered also important. Therefore, signal paths within the instrument were carefully designed to reduce emissions. For instance, a linear power supply was chosen, not only for simplicity and ease of repair, but also for its quiet nature. Also important were precautions such as keeping signal loops and ground returns tightly spaced, and the fact that most of the high-speed logic was shrunk into the MRC. Most signals that have to travel long distances are converted to sine waves to reduce harmonics. The result was an excellent EMI compatibility and the 5335A passed Germany's VDE 0871/0875, FTZ 526/1979, 527/1975 receiver law limits, and the U.S. MIL-STD-461A Notice 3 limits.

Besides its features, the 5335A was one of the new “light” instruments; I measure them in binary form: can I put it on the shelf by myself (Class B) or must I to call my son for help (Class A)? This is definitely a Class B instrument, and I can easily move it where I need. However, if you are tied to ancient conceptions, I say that its weight is 13.6 kg.

The general quality is good, as you can see from the photos, with the typical enclosure of many other HP instruments. As an example of durability, I want to mention the original Papst fan (in the photo). Although rather noisy, it is a little tornado, and, even if it looks like many modern Chinese units, it is in die cast aluminum and imperishable. I don’t know how long it stayed on in its life, but in 43 years (my unit is from 1981), I strongly believe it worked a lot…

In the photo: the typical HP fan, robust and durable.

Service Tips

Luckily, my 5335A had almost no problems, so I limited my activity to very few points.

Voltages

Besides cleaning, I wanted to check the voltages, as always I do, as a rule. The 5335A power supply contains seven de supplies: +25 volts, +15.7 volts, -15 volts, +15 volts, +10 volts, +5 volts, +3 volts, and -5.2 volts. These supplies are generated in the A1 assembly; you should verify that they are within tolerance per manual Table 8-7. In case of problems, the 4 MHz microprocessor oscillator should be checked, as well as the 10 MHz timebase oscillator (manual 8-423). There is a place where you can check them easily, the connector J1 on the A1 board, shown in the photo here.

In my case, I found the voltages rather precise and clean, i.e., with a very small ripple.

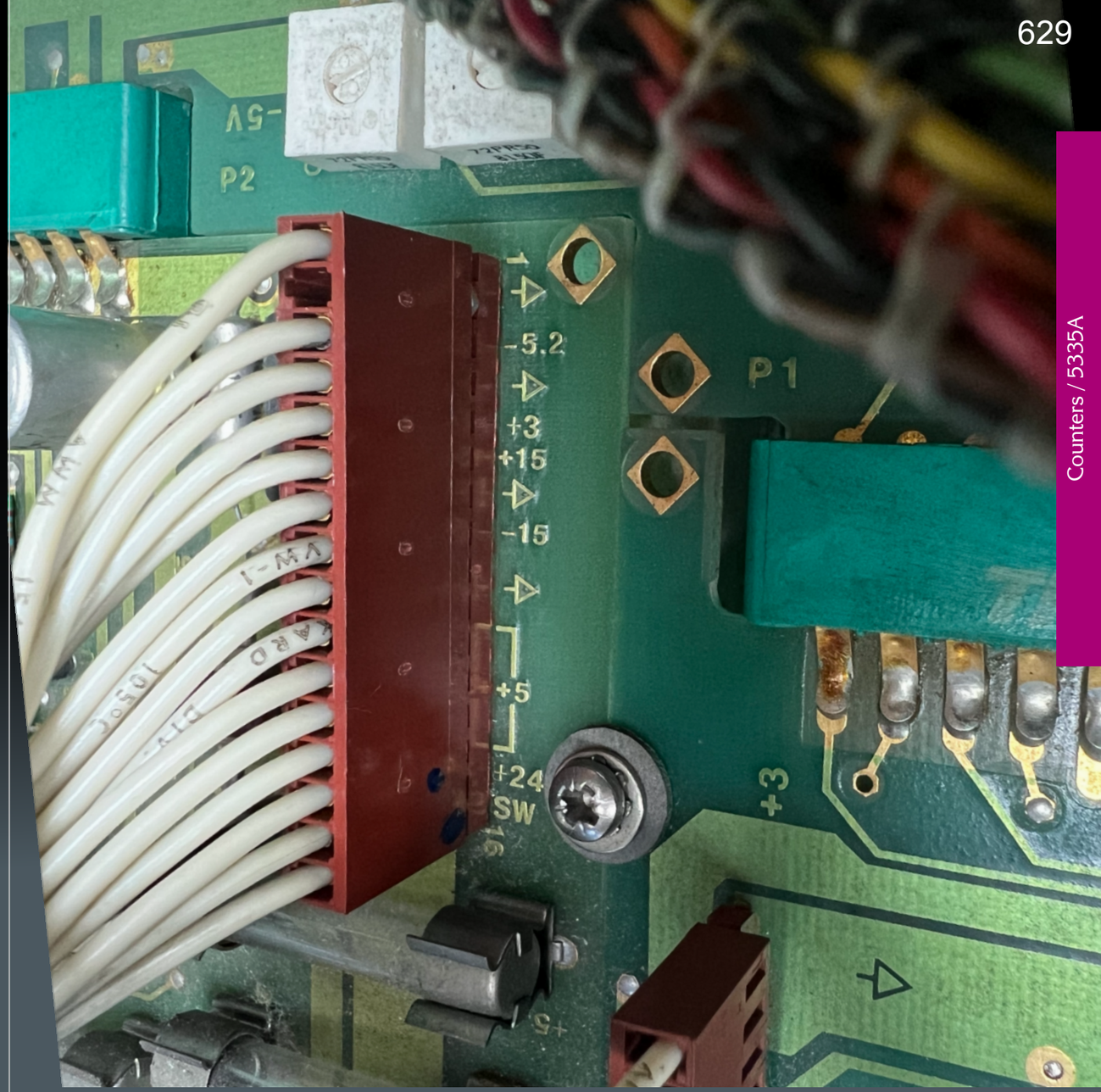
Diagnostics

The 5335A is very well conceived from the maintenance point of view. The software provide us with plenty of diagnostic routines which serve to verify, by self-check, various functional subsections of the counter's circuitry. They can be selectively activated, in isolated loops, to allow on-line testing.

A good self test is performed at power-up, so the fact that the instrument goes into service already indicates that many tests have been carried out.

Signature Analysis

That was the time when Signature Analysis was widely used; the 5335A provides specified diagnostic routines, which allow on-circuit troubleshooting to component level. All instructions, signatures, and physical Test-Points are provided in the manual. I don't have a SA tool; should it be necessary, even modern solutions are available on the market (not very cheap).



Super Check

The SUPER CHECK (Diagnostic #01) is a continuous diagnostic loop which will repeat until manually reset; during this cycle the front end amplifiers are checked for accuracy, cross talk, attenuation and separate/common with the input signal. In addition the 5335A checks the operation of the following:

- ROMS RAMS
- DATA BUS
- FRONT PANEL DISPLAY
- MRC
- INTERPOLATORS
- TRIGGER LEVEL REFERENCES (GND, +5V, -5V)
- CHANNEL A & B TRIGGERING
- SEP/COM RELAY
- PRE-SCALER
- POWER SUPPLY VOLTAGES (+5V, +3V, -5.2V)

To perform the SUPER CHECK proceed as follows:

a. Connect a 4-foot BNC cable from the 5335A rear panel TIME BASE OUT to the front panel INPUT A jack. Set the 5335A 1 MΩ/50Ω input control to 50Ω.

b. Call up Special Function 99 by pressing the following 5335A keys:

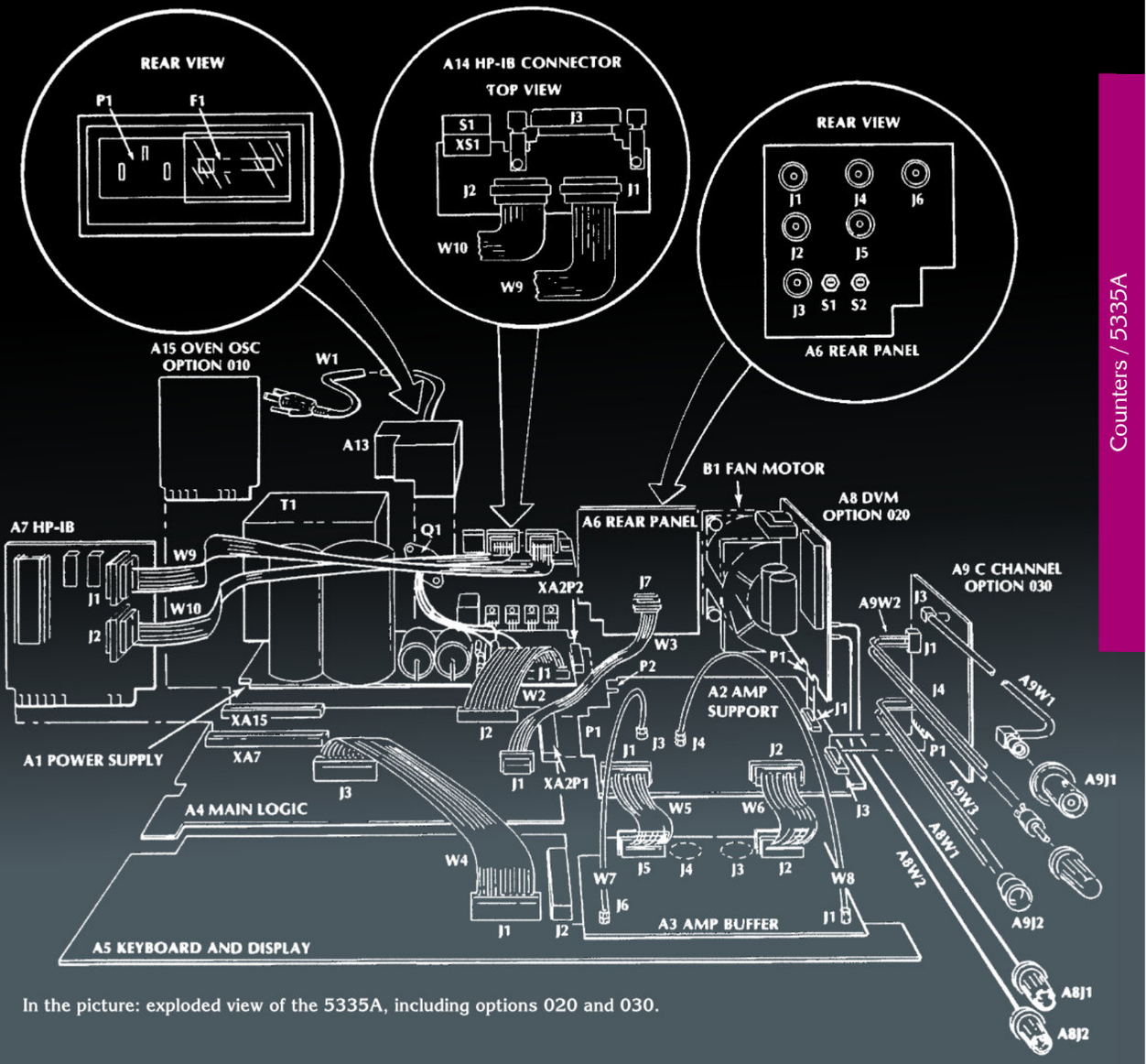
- SCALE (verify the SCALE key lamp is flashing); SMOOTH (Display will show "SPECIAL +0"); "99"; ENTER (Display will show "dIAG 01" for about 5 seconds.

All display annunciator lamps turn ON for about 5 seconds. Successful completion of the front end test loop displays the message "FE PASS" for about 15 seconds.

Display shows nominal values of 3 Supply

- 5.000 00 V
- 3.000 00 V
- -5.200 00 V

The test then repeats itself. If TIME BASE OUT is not connected to INPUT A, ERROR 7.0 will be displayed. The manual, at para 8-254, supplies a detailed description of each test.



In the picture: exploded view of the 5335A, including options 020 and 030.

A True Keyboard

I Like It!

I am more and more hating touch screens. Recently I had to buy a new car, otherwise a good car, where almost every control is done by touch. Even for the air recirculation, you must navigate trough its silly menus. With the inevitable shocks that the road produces, your finger often ends activating what was not in your intentions. Maybe that in the future, users become to reject this ubiquitous interface (by the way: it has also a very dangerous lane control that you must disable every time you start).

Wonderfully the 5335A has a key for almost any function, like the cars of the good old days, and, in addition, this type of keyboard is my preferred one. In this case, many keys have also a LED inside, to signal wether the labeled function is activated or less.

A Routine Job

With all these instruments that share a common look, a dedicated service for the keyboard is mandatory. The reasons to do that are at least two:

- they are always dirty, with an horrible black row all around, which makes our friends to look old and ugly; unbearable!
- all the keyboard of this type do a terribly unprofessional “clack” sound when they get old, which triggers my sensitivity; it’s like to listen a crying baby…All the keyboards of this type I had the opportunity to deal with had this problem.

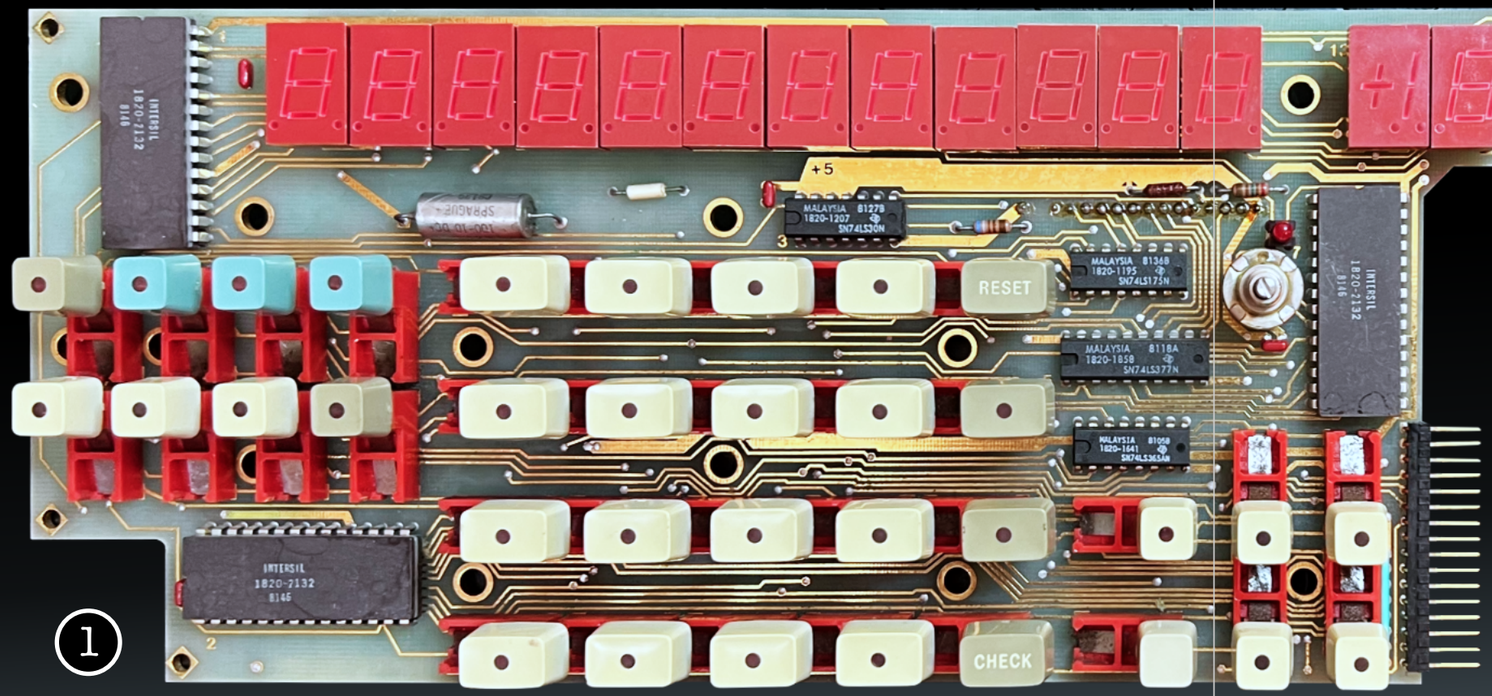
The solution is not complex: just dismount the keyboard, flood the contacts with WD40C and exercise the keys a number of times. The touch will return almost as on a new keyboard (as always, I warn you about the “C” - never use normal WD40!).



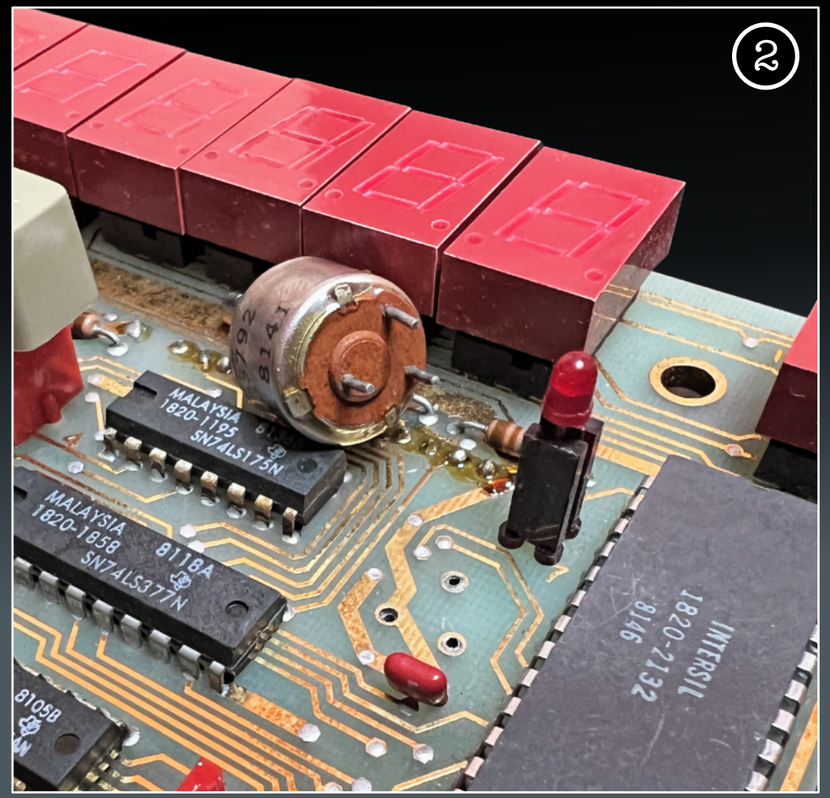
This keyboard, differently from those of other similar instruments, it is held together with springs instead of screws. However, they are quite easy to put on and to remove by squeezing them with simple tweezers.

❶ The 5335A main keyboard (another is present on the A3 Amplifier/Buffer Board). See the text on the previous page for its servicing. The 1820-2132 ICs are LED drivers and are replaceable with ICM 7218, still today available).

❷ On this board there is also a potentiometer (GATE ADJ). Strangely, it is mounted on socket, as shown in this photo.



1



2

Keyboard Details

Special Functions

Phantom Functions

I like keys very much, as opposite to modern touch scree. The 5335A front panel allowed for a direct, key-per-function selection from 16 labeled function operations. A sequence of keystrokes allowed the operator to enter a Special Function Mode, in which the original 16 functions, plus 4 additional unlabeled functions and an extensive diagnostic mode can be accessed. The four unlabeled "phantom" functions are:

- FREQ B (code 17)
- TIME B—A (code 18)
- TOT A-B (code 19)
- PULSE B (code 20)

The diagnostic mode we saw earlier allowed the user considerable flexibility during troubleshooting through a set of discrete, self-diagnostic test routines. These functions are accessed via the HP-IB through the normal FN or FU command, however, they may also be accessed manually through the keyboard. This is an example of invoking FREQ B, function 17:

- Press: SCALE, SMOOTH, 1, 7, ENTER

After pressing SMOOTH the display will show the word "SPECIAL". After pressing ENTER the counter will be in FREQ B. No function lamp indication is given for these special functions.

When using TOTALIZE A-B output is given only after the gate is closed. To start the totalizing, a pulse from B must first be received. Closing the gate is also synchronized with a pulse from Channel B.

I wanted to test them: they works. Note only that TOT A-B does not show the result in real time, but only when you close the gate.

In the picture: the 5335A filter capacitors. Today they could be much smaller, but with them the landscape is wonderful... Note also the 2N3055 used for the linear voltage regulator and the relay that switches on when we pass from stand-by to operation. You can see also the main processor (1820-2099) and the mythical MRC chip (1820-2312), which is not a Motorola 6508 as someone says, but an ECL LSI chip, specifically designed by HP for this kind of applications. The most valuable components are mounted on sockets.